DOCUMENT RESUME

ED 132 024 SE 021 503

TITLE	A National Plan for Energy Research, Development & Demonstration: Creating Energy Choices for the Future, 1976. Volume 1: The Plan.
INSTITUTION	Energy Research and Development Administration, Washington, D.C.
REPORT NO	ERDA-76-1
PUB DATE	76
NOTE	125p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Number 052-010-00478-6, $2.00)
EDRS PRICE	MF-$0.83 HC-$6.01 Plus Postage.
DESCRIPTORS	*Energy; Energy Conservation; Government Publications; *Government Role; *National Programs; *Planning; *Research; Science Education; Scientific Research; Solar Radiation; Technology
IDENTIFIERS	*Energy Research and Development Administration; ERDA

ABSTRACT

This report presents a plan developed by the Energy Research and Development Administration (ERDA) concerning future energy sources. The plan summarizes ERDA's current views on the energy technologies the U.S. will need to achieve long-term energy independence. The role of the private sector in the development and commercialization of new energy technologies is addressed, and conservation technologies are ranked with supply technologies as the highest priorities for national action. (MH)

****
* Documents acquired by ERIC include many informal unpublished *
* materials not available from other sources. ERIC makes every effort *
* to obtain the best copy available. Nevertheless, items of marginal *
* reproducibility are often encountered and this affects the quality *
* of the microfiche and hardcopy reproductions ERIC makes available *
* via the ERIC Document Reproduction Service (EDRS). EDRS is not *
* responsible for the quality of the original document. Reproductions *
* supplied by EDRS are the best that can be made from the original. *
****

ERDA 76-1

A NATIONAL PLAN FOR ENERGY RESEARCH, DEVELOPMENT & DEMONSTRATION: CREATING ENERGY CHOICES FOR THE FUTURE 1976

VOLUME 1: THE PLAN

ED132024
SE 021 503

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

2

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D.C. 20545

April 15, 1976

The President of the United States

The President of the Senate

The Speaker of the House of Representatives

Sirs:

I enclose for your consideration Volume I of ERDA 76-1, "A National Plan for Energy Research, Development, and Demonstration - Creating Energy Choices for the Future" containing the Plan. Volume II, the Program Implementation (including both nonnuclear and nuclear programs) will be forwarded under separate cover at a later date, expected to be within the next 30 days.

This is the first annual update of the initial report submitted to you in June 1975 (ERDA-48), and complies with the requirements of Section 15 of the Federal Nonnuclear Energy Research and Development Act of 1974.

This report represents an evolution in approach over the previous document. ERDA's proposed National Plan has been expanded in scope and depth of coverage and the basic goals and strategy are refined, but remain essentially intact. The Plan summarizes ERDA's current views on the energy technologies the Nation will need to achieve longer-term energy independence, specifically:

- o The paramount role of the private sector in the development and commercialization of new energy technologies is addressed.
- o Conservation (energy efficiency) technologies are singled out for increased attention and are now ranked with several supply technologies as being of the highest priority for national action.
- o The President's 1977 budget requests a large increase - 30% over 1976 - in funding for energy RD&D with particular emphasis on:
  - accelerating energy RD&D programs directed at achieving greater long-term energy independence,

- encouraging cost-sharing with private industry and avoiding the undertaking of RD&D more appropriately the responsibility of the private sector,

- supporting the commercial demonstration of synthetic fuel production by providing loan guarantees beginning in FY 76.

o Federal programs to assist industry in accelerating the market penetration of energy technologies with near-term potential are a key element of the Plan.

The Executive Summary outlines specific conclusions and recommendations that are presented more fully in the body of the report.

I believe it is important that we achieve extensive Congressional and public discussion of the national energy research, development and demonstration considerations and recommendations contained in ERDA-48 and described in further detail in the present report. Such public discussion is an essential part of the common effort to arrive at an effective approach to the solution of our energy problem - an approach that in terms of research, development and demonstration is based on the concept of creating energy choices for the future.

Sincerely,

Robert C. Seamans, Jr.
Administrator

ERDA 76-1

A NATIONAL PLAN FOR ENERGY RESEARCH, DEVELOPMENT & DEMONSTRATION: CREATING ENERGY CHOICES FOR THE FUTURE 1976

VOLUME 1: THE PLAN

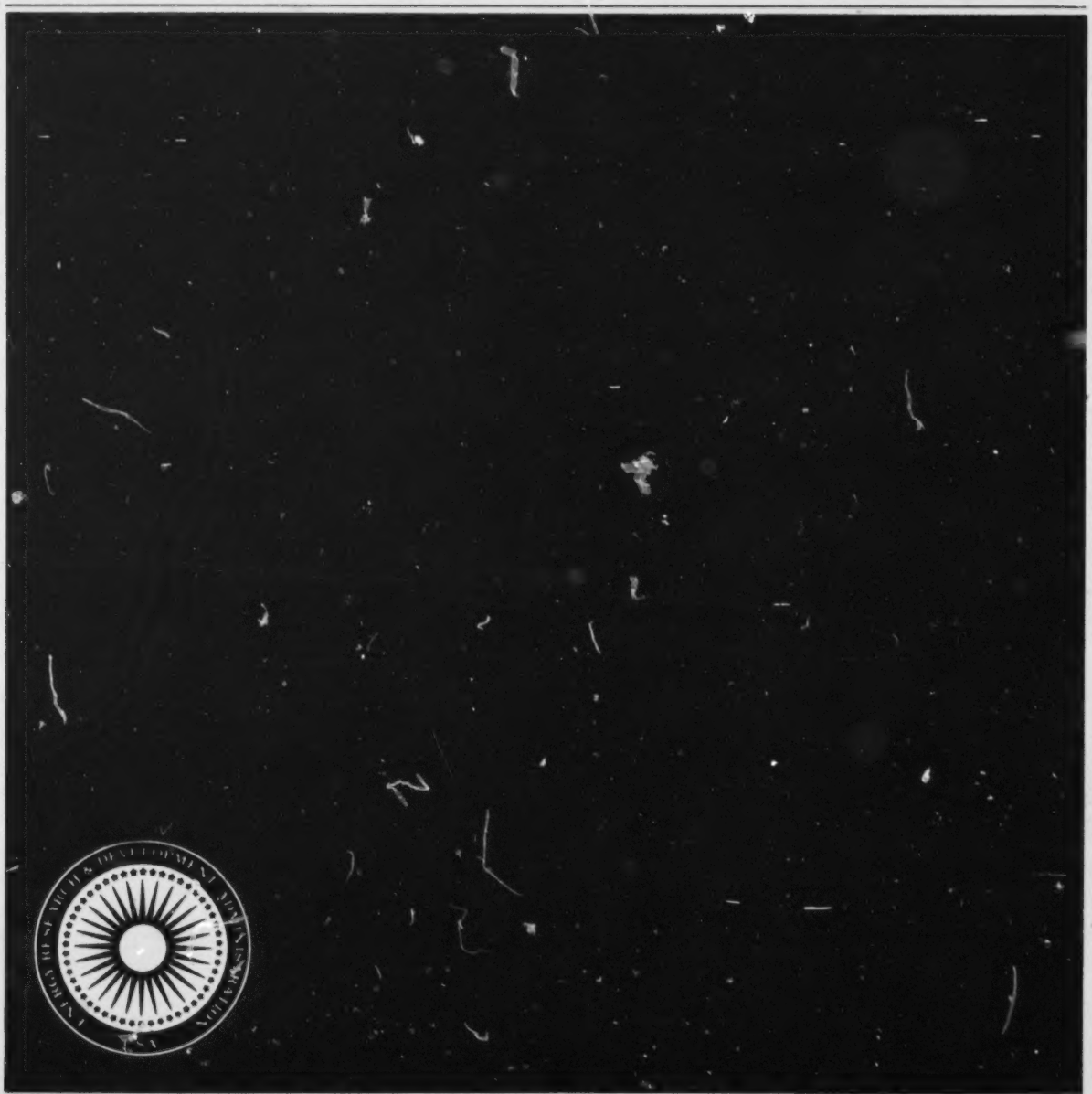


Table of Contents

Preface vii

Executive Summary 1

Chapter I—The National Energy Problem and the Nature of Its Solution 15

—The Role of the Private and Public Sectors 16
—The Role of Federal Agencies 18
—The Role of ERDA 19

THE PLAN

Chapter II—Fundamentals of the Plan 23

—National Policy Goals Related to Energy 23
—National Energy Technology Goals 24
—Strategy and Priorities for RD&D 27
—Specific Supporting Technologies 30
—Basic Energy Science and Environmental Research 31

Chapter III—The Plan and The Federal Energy RD&D Program for FY 1977 35

—The FY 1977 Budget 35
—Chief Programmatic Thrusts 43
—Conservation Technologies 43
—Light Water Reactors 47
—Enhanced Oil and Gas Recovery Techniques 51
—Direct Utilization of Coal 52
—Synthetic Liquid and Gaseous Fuels 55
—Geothermal 59
—Solar Heating and Cooling in Buildings 62
—Breeder Reactor 64
—Fusion 66
—Solar Electric 67

Chapter IV—Implementing the Plan: Interrelationships Among Energy RD&D Participants 69

—Developing International Agreements 70
—Improving Federal Agency Interaction 71
—Strengthening the Private Interface 73
—Expanding Interaction with State and Local Governments 77
—Establishing the Regional Interface 78

Chapter V—Implementing the Plan: ERDA Planning System 81

—PPBR System Structure 81
—PPBR System Outputs 85

DEVELOPING THE PLAN

Chapter VI—Factors Influencing the Evolution of the Plan 89

—International and Domestic Events 89
—Assessment of the Plan by Others 94
—Energy Systems Analysis Studies 95

Chapter VII—Future Evolution of the Plan 105

—Developing Energy RD&D Costs and Benefits 105
—Establishing Priorities for Component Programs 105
—Analyzing Energy RD&D Activities in the Private Sector 106

Appendices

A—Perspective on World Resources 107
B—Net Energy Analysis of Nuclear Power Production 111

Glossary 117

Selected Bibliography 121

Preface

In the 1975 State of the Union message, President Ford enunciated three national energy policy goals necessary for the Nation to regain energy independence. These goals are reiterated in the 1976 Energy Message:

—"First, to halt our growing dependence on imported oil during the next few critical years.

—"Second, to attain energy independence by 1985 by achieving invulnerability to disruptions caused by oil import embargoes. Specifically, we must reduce oil imports to between 3 and 5 million barrels a day, with an accompanying ability to offset any future embargo with stored petroleum reserves and emergency standby measures.

—"Third, to mobilize our technology and resources to supply a significant share of the free world's energy needs beyond 1985."

The following principles guided the development of the program. These principles are still sound today:

—"Provide energy to the American consumer at the lowest possible cost consistent with the need for secure energy supplies.

—"Make energy decisions consistent with our overall economic goals.

—"Balance environmental goals with energy requirements.

—"Rely upon the private sector and market forces as the most efficient means of achieving the Nation's goals, but act through the government where the private sector is unable to achieve our goals.

—"Seek equity among all our citizens in sharing of benefits and costs of our energy program.

—"Coordinate our energy policies with those of other consuming nations to promote interdependence, as well as independence."

New technology that will help expand domestic energy supplies and improve the efficiency of energy use is an essential tool in achieving the President's energy goals. The introduction of new technology requires, in turn, a major national effort in research, development and demonstration (RD&D), carried out largely in the private sector but supplemented by government-sponsored RD&D where necessary.

In June 1975, the Energy Research and Development Administration (ERDA) submitted to the President and the Congress a report entitled **A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future (ERDA–48).**

Within the context of the President's goals for energy independence, the 1975 plan:

—Recommended energy R&D goals and objectives for the Nation.

—Examined the potential timing and contribution of major energy technology options.

—Ranked major technologies and related them to their potential energy contribution in the near, mid and long-term.

—Discussed Federal and private sector roles in energy RD&D and described the Federal energy RD&D effort.

The Plan also served as an important input to the development of the President's amended 1976 and the 1977 budget request for energy RD&D funding.

While ERDA's proposed plan is national in scope, the Federal Government can neither unilaterally plan the course of national action nor accomplish all the necessary actions defined by such a plan. This planning process is a useful mechanism because the Federal Government can use such an approach as one context for its own actions and as a way to promote consensus on the Nation's approach to energy RD&D. In this regard ERDA–48 contributed to this planning process in the following three ways:

1. By establishing a likely order of technology introduction from the near to the long term, ERDA–48 identified current major guideposts for measuring and assessing the rate of technology introduction. These guideposts can be useful in evaluating whether enough new technologies are being introduced to solve the Nation's

energy problem, and in identifying possible compensatory government action.

2. ERDA–48 proposed national energy RD&D priorities linked directly to this order of technology introduction. These national priorities are intended to be generally helpful in evaluating the national energy RD&D effort. In particular, the priorities bear on the allocation of government RD&D resources.
3. It stimulated debate on the technological options open to the Nation in the context of the total energy problem. ERDA believes this context, which forces the weighing of all alternatives together, facilitates the objective evaluation of individual technologies. It is a debate that should be encouraged.

Accomplishment of the activities identified in the proposed national plan needs: 1) agreement of the private sector and the public on the planning approach, and 2) acceptance of both the role and the sets of actions set forth in the plan to be carried out by these entities. Thus, the development of a national planning approach must be iterative and dynamic. Newly discovered energy supplies, changes in energy policy, scientific successes and failures, economic conditions, actual progress in introducing new technology—all these and more will change the Plan. Recognizing these dynamics, the Congress instructed ERDA to report annually on its progress during the past year, and to revise annually its Plan and program.

This document is the first such annual report and Plan revision. Because it ranges widely, although not exhaustively, across the energy problem and energy RD&D, this revised Plan carries many themes. However, it returns repeatedly to the central theme that the development and introduction of new energy technology requires the interaction of many programs, institutions, and individuals.

Accordingly, **Chapter I** of ERDA 76-1 presents an overview of the energy problem and the major requirements for its solution. It then describes at some length the relative roles of the participants in the solution and why—and how—the players must work together.

The next two chapters present the revised Plan and program. **Chapter II** describes the Plan—a likely ordering of technology introduction and the related national RD&D priorities. This revised Plan is not much different from ERDA–48. Substantively, the higher national priority assigned to conservation is the major revision. Additionally, this chapter restates and attempts to clarify some of the ERDA–48 material.

Chapter III summarizes the Federal energy RD&D program, which, of course, is only one part of the national activity under way. This chapter develops two important points. First, it discusses Federal RD&D program strategies, emphasizing programs nearing the point of market penetration. The interaction of Federal RD&D with the private market is a unique and crucial aspect of ERDA's mission. Second, this chapter presents the FY 1977 Federal energy RD&D budget. (Volume II of this Plan, published separately, contains more detail on last year's progress and future prospects for each of the energy RD&D programs.)

Chapters IV and V turn to the institutional mechanics necessary to implement the Federal RD&D and program. **Chapter IV** discusses the interactions between ERDA and the public, the private sector, state and local government agencies, other Federal Government agencies, and other countries. Successful interaction will increase the likelihood of early development and implementation of new energy technologies and realization of the Nation's energy goals. **Chapter V** describes the key elements of the analysis and planning system being developed and implemented by ERDA.

The final chapters of this report will be of special interest to those who want to follow closely the analytic foundations of the Plan. **Chapter VI** discusses the events, public comments, and new analytic results that have impact on or have shaped the Plan, and explains why Plan revisions were made; similar material will be included in all future editions of the Plan. **Chapter VII** looks to the future, presenting ERDA's current views of priority matters to be treated in greater depth in the next Plan update.

Executive Summary

Key Points of The Summary

Representing an evolution in approach over the initial planning of June, 1975, this National Plan expands the scope and depth of coverage of the earlier Plan. The basic goals and strategy are refined, but remain essentially intact.

Significant points of emphasis in this report are as follows:

- The paramount role of the private sector in the development and commercialization of new energy technologies is addressed.
- Conservation (energy efficiency) technologies are singled out for increased attention and are now ranked with several supply technologies as being of the highest priority for national action. The primary responsibility for developing and bringing into use improved technologies for energy efficiency rests with the private sector but the Federal Government is increasing its funding for this area to provide encouragement and stimulus to the total national effort.
- Federal programs to assist industry in accelerating the market penetration of energy technologies with near-term potential are a key element in the Plan.
- The close coordination of technology development with socioeconomic and environmental factors, at regional as well as national levels, is provided.
- The President's 1977 Budget recognized the high priority of energy RD&D by proposing a greatly expanded program at a level appropriate to the responsibilities of the Federal Government. Specifically, it:
  - —Accelerated energy RD&D programs directed at achieving greater long-term energy independence.
    - ——Expanded efforts to assure the safety, reliability, and availability of commercial nuclear power plants.
    - ——Placed greatest funding on technologies with the highest potential payoff in terms of recoverable resources (i.e., nuclear and fossil).
    - ——Greatly increased the Federal investment in conservation technologies.
    - ——Continued to expand the investigation of other technologies where they can make significant contributions to meeting the long-term energy requirements of the U.S. (i.e., solar, and fusion).
  - —Encouraged cost-sharing with private industry (e.g., coal liquefaction demonstrations) and avoided undertaking RD&D more appropriately the responsibility of the private sector (e.g., in areas of conservation technology).
  - —Supported the commercial demonstration of synthetic fuel production from coal, oil shale, and other domestic resources by providing loan guarantees beginning in FY 1976.
- A new short-term, five-year-forward planning category is added to the Plan to focus attention on opportunities for technology development that may have effect within five years.

National priorities for energy RD&D are not the same as priorities for the allocation of *Federal* funds for energy RD&D. In many cases, Federal spending for the development of a particular energy technology may not be justified because:

- —the RD&D function can better be performed by the private sector,
- —the objective can better be achieved by some means other than RD&D, or
- —the funding required is not sufficiently high in priority compared to other demands for Federal funds.

Furthermore, the level of Federal resource commitment for any particular area of energy technology is also influenced by the stage of technology development as a technology moves from the less expensive research phase to the more expensive pilot and demonstration plant phases.

While ERDA's proposed plan is national in scope, the Federal Government can neither uni-

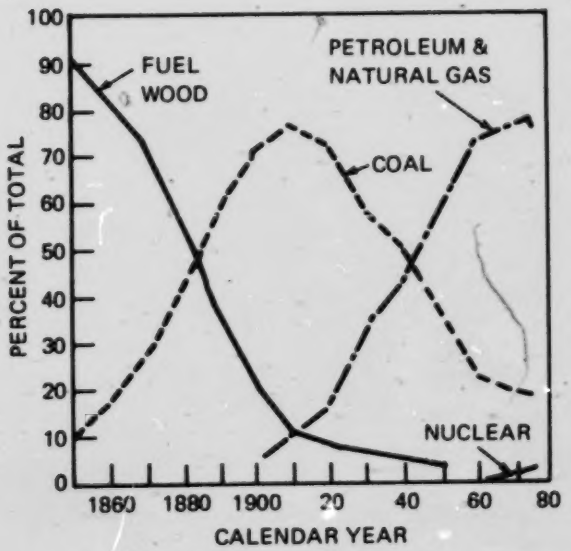
laterally plan the course of national action nor accomplish all the necessary actions defined by such a plan. This planning process is a useful mechanism because the Federal Government can use such an approach as one context for its own actions and as a way to promote consensus on the Nation's approach to energy RD&D.

Background of the Plan

The Nation faces a serious and continuing energy problem characterized by limited energy choices and increasing dependence on diminishing oil and gas resources. This problem is currently exemplified by an undue reliance upon imported fuels.

This serious energy problem has come about because most of the fuel currently used by the Nation is in the form of petroleum and natural gas, and these fuel resources are becoming rapidly depleted. Actions must be initiated to prepare for a transition from dependence on oil and gas to reliance on alternative energy sources, particularly coal and nuclear in the near and mid term. Historically, however, such transitions, as illustrated in Figure I, have required more than half a century.

To provide alternatives to undesirable dependence on oil and gas, the Nation must undertake a program of technology development which will be technologically difficult and costly, and will require time.



SOURCE: HISTORICAL STATISTICS OF THE UNITED STATES BUREAU OF THE CENSUS; U.S. BUREAU OF MINES, 1974

Figure I U.S. Energy Consumption Patterns

The problems of transition to new energy sources are difficult. New domestic energy sources are potentially available—indeed, solar energy and nuclear fission (breeder) and fusion represent essentially inexhaustible energy sources—but there are significant economic, environmental, social and technological problems to be solved before these new energy sources can become adequate supplements for oil and gas. Meanwhile, existing domestic alternatives in such forms as abundant coal resources, and the full benefit of nuclear light water reactors cannot be completely realized without further technological improvements.

Figure II presents current potentially recoverable resource estimates for key domestic fuels. Shaded areas indicate the additional resources that may become recoverable if the necessary technology and utilization techniques can be developed. In addition, Figure II illustrates the relative paucity of domestic oil and gas resources compared to the estimated cumulative energy demand from now until the end of the century. Coal and nuclear represent the major exploitable resources to supplement oil and gas over the next several decades. Geothermal, oil shale, and solar energy in the form of solar heating and cooling represent supporting resources to ease overall supply problems in that same time period. Nuclear breeders, solar electric, and fusion represent technologies that can exploit major resources for the next century. These latter three technologies differ significantly as to the status of their development and demonstration, the severity of the economic, environmental, social and technological challenges to be overcome and their potential for meeting energy needs within given time frames. With respect to the latter point, the first two of these have the potential to contribute to meeting energy needs during the later part of this century.

In summary, even though the Nation is blessed with abundant energy resources, it is currently dependent upon a narrow base of diminishing resources.

This Plan is designed to describe likely options for the introduction of new technology that will assist the changeover from dependence on this narrow base of diminishing domestic resources to reliance on a broader range of less limited alternatives.

The transition to less limited resources poses substantial technological and environmental problems. Of equal importance are the difficult economic, social, and institutional problems that will be associated with this transition. These problems must be addressed more intensively than ever before and a RD&D program, however successful technically, can fail because of failure to solve any one of these problems.

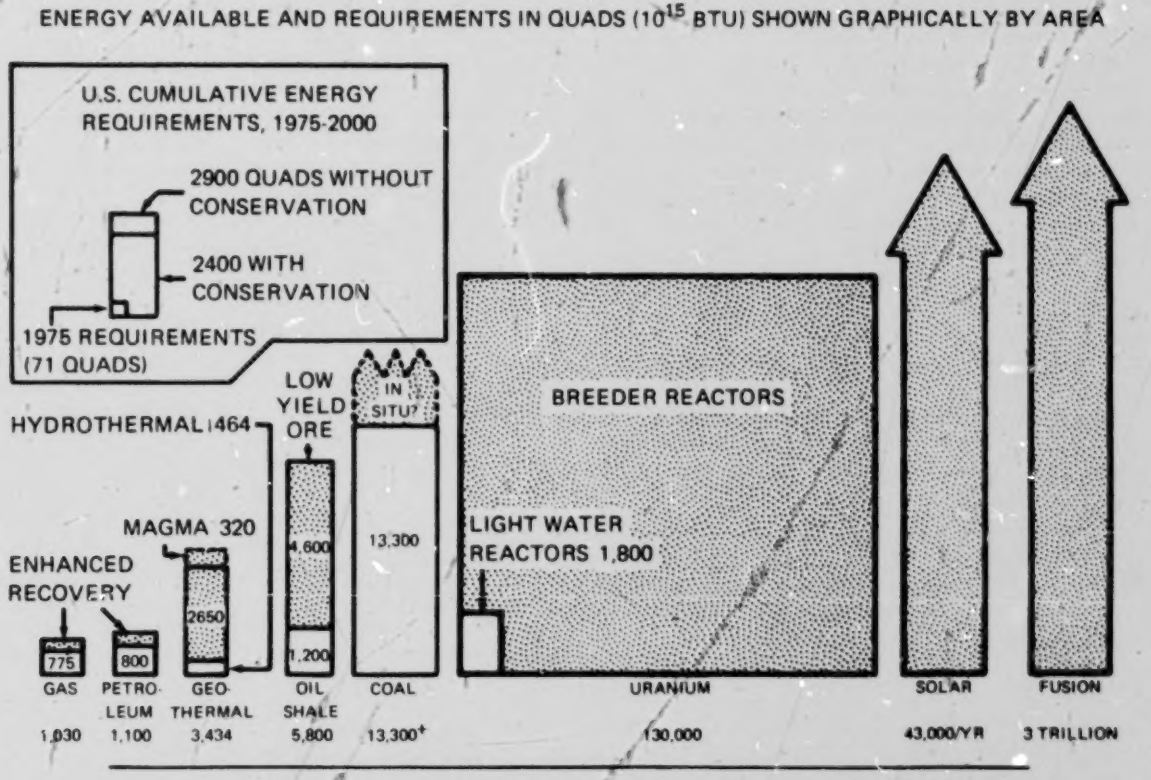


Figure II Potentially Recoverable Domestic Energy Resources

Technology development is made more difficult by uncertainty as to how the future will evolve with respect to energy demand, energy costs and many other factors. There is, today, uncertainty as to the future of energy demand; the relative economics of energy technologies; the interplay with the environment; the choice of preferred energy systems; the date of introduction or the rate of implementation of a particular energy technology; the international aspects of the world-wide energy problem; and other factors affecting solution to the domestic energy problem.

While technological development is a necessity for almost every aspect of the energy problem, the design of a program for technology development must remain responsive to such factors as:

- How much domestic oil and gas is actually found and produced
- The availability of imports from secure sources, plus the backup protection against supply disruption that can be gained from stockpiling policy
- The rate of implementation and level of development of both existing and emerging new technologies
- The degree of protection afforded human health and the physical environment
- The degree of modification of life styles which the Nation finally adopts
- The end-use energy efficiencies that may be finally attained
- The level of effort that can be placed in the development of new technology
- The economic and technical success finally achieved by new technologies
- The impact of economic and sociopolitical considerations.

Even though this list is not exhaustive, it is illustrative of the difficulties in dealing with the energy problem. Decisions on this development must be made today in the face of uncertainty, without foreclosing future options. Indeed, the basis for undertaking a program of energy RD&D is to broaden the Nation's range of available energy options—**to create energy choices for the future.**

While RD&D is clearly needed, an insufficient amount is being conducted in the private sector because of uncertainties with respect to future profitability; environmental standards and other regulatory policies; the magnitude of technological risks being faced; the lack of present institutional organizations to undertake the effort; or simply because of the sheer size of the effort or investment. Energy RD&D

is one element of the total National policy which must seek to reduce these risks and uncertainties and improve the economic and regulatory climate for private action.

The starting point for this Plan for technology development is the broader concept of national energy goals and principles.

Ultimately, decisions as to which technologies are found to be acceptable have wide-ranging implications for the country's security, and involve the future environmental and economic well-being of all citizens. The process of developing alternatives to the present energy system needs to be carried out in a context which continually considers the broader issues of public concern.

The programs to achieve Energy Independence were guided by the following principles: These principles are still sound today:

- "Provide energy to the American consumer at the lowest possible cost consistent with the need for secure energy supplies.
- "Make energy decisions consistent with our overall economic goals.
- "Balance environmental goals with energy requirements.
- "Rely upon private sector and market forces as the most efficient means of achieving the Nation's goals, but act through the government where the private sector is unable to achieve our goals.
- "Seek equity among all our citizens in sharing costs and benefits of our energy program.
- "Coordinate our energy policy with those other consuming nations to promote interdependence, as well as independence."

In keeping with the above principles, the President set forth the following goals for a comprehensive national energy effort in the 1976 Energy Message:

—First, to halt our growing dependence on imported oil during the next few critical years.

—Second, to attain energy independence by 1985 by achieving invulnerability to disruptions caused by oil import embargoes. Specifically, we must reduce oil imports to between 3 and 5 million barrels a day, with an accompanying ability to offset any future embargo with stored petroleum reserves and emergency standby measures.

—Third, to mobilize our technology and resources to supply a significant share of the free world's energy needs beyond 1985.

It is the purpose of the National Plan for Energy RD&D to translate these principles and goals into specific Federal programs for technology development, recognizing that industry initiatives in implementing this development will be of paramount importance and that the public's support as citizens and consumers is essential.

A basic premise in national energy policy and planning for RD&D is that the private sector has the primary role in creating new energy alternatives; the Federal Government's role is to assist the private sector in the development and market penetration of new energy technologies.

With few exceptions, the private sector is the main producer and consumer of energy. The role of the private sector is therefore paramount in the accelerated introduction of energy technology, and in the solution of the Nation's energy problem.

In part, this is so because the private sector is motivated and prepared to take the risks involved in developing and introducing new energy technologies. In addition, the private sector has the inherent flexibility to act; the preponderant share of new investment funds; and the managerial capabilities for carrying out most of the RD&D and virtually all of technology introduction. Moreover, market forces as they are perceived by decision-makers in the private sector will determine the economically optimal mix of alternative energy technologies to displace the undue reliance on petroleum and natural gas.

Therefore the establishment of the Federal program and activity levels, the objectives are:

- To assist and reinforce private sector actions rather than to compete with them
- To ensure relevance of governmental activity by achieving extensive private sector involvement at the earliest possible moment in the development cycle.

An important theme of this report is that the private sector and market forces are the most efficient means of achieving the Nation's energy goals.

The role of the public sector, especially that of the Federal Government, is therefore supplementary—to do what cannot otherwise be done privately. The Federal role, in turn, divides into three parts: Government can establish an appropriate policy climate for private sector action, share risks, and conduct a complementary RD&D program.

In general, a preferred role of government is to establish an appropriate climate for private introduction of energy technology, such as:

- **Leadership and assistance:** establishing a consistent and stable policy and regulatory network.
- **Management of energy resources located in Federal lands:** making available these resources for use over time with due regard to environmental, aesthetic, conservation, land-use, or other factors of national interest.
- **Economic and anti-trust regulation:** making energy decisions consistent with national economic goals; providing energy consistent with the need for secure energy supplies; and assisting in the devel-

opment of standards, criteria, and certification procedures.

- **Human health, safety, and environmental Protection:** ensuring the protection of the Nation's environment and the public's health and safety.
- **International policy:** coordinating our energy policies with those of other consuming and producing nations tc promote interdependence as well as independence.

Within the Federal Government, ERDA has specific leadership responsibility in energy RD&D.

Energy RD&D is an important component of the total Federal role, and ERDA plays a leadership role here in three ways.

First, ERDA develops and updates the National Plan for Energy RD&D. This Plan cannot, and is not intended to, represent technology as a total solution to the energy problem, nor can it predict certain success for any particular program, ensure immediate results, or preselect a single energy future. Rather, the Plan performs three principal functions:

1. Establishes a likely order of technology introduction from the near to the long term, and identifies current major guideposts for measuring and assessing the rate of technology introduction. These guideposts are useful in determining whether enough new technologies are being introduced to solve the Nation's energy problem, and in identifying possible compensatory government action.
2. Proposes national energy RD&D priorities linked directly to the order of technology introduction. These priorities are intended to be generally helpful in evaluating the national energy RD&D effort. In particular, the priorities bear on the allocation of government RD&D resources.
3. Stimulates debate on the technology options open to the Nation in the context of the total energy problem. ERDA believes this context, which forces the weighing of all alternatives together, facilitates the objective evaluation of individual technologies. It is a debate that should be encouraged.

Second, ERDA has the responsibility to monitor and report on the entire Federal energy RD&D effort. In this way, a coordinated program aimed at common objectives is more likely to emerge. Volume II of this Plan summarizes the activities of 23 Federal agencies as they relate to the total RD&D program.

Finally, ERDA is itself the principal sponsor of Federal energy RD&D, including programs involving risk-sharing with the private sector.

Fundamentals of the Plan

To propose effective solutions to the Nation's current energy problem, the National Plan for Energy RD&D addresses technology development from the standpoint of both private sector and Federal Government activities, and also proposes approaches to incorporate pertinent nontechnological considerations which can affect the results of RD&D.

The National Plan for Energy Research, Development and Demonstration is an integral part of an overall approach for addressing the Nation's energy needs. It is responsive to the national energy policy goals and principles enunciated in the President's 1975 State of the Union Message, and reiterated in the 1976 Energy Message. While its emphasis is on technological development, it is consistent with and reflects broader policy concerning import levels, foreign relations, the needs of industry and consumers, fiscal policy, environmental protection, and human health and safety concerns.

In its initial response to the Nation's energy needs, the Energy Research and Development Administration (ERDA) formulated the first National Plan for Energy RD&D, which proposed national priorities for the development of new energy technologies. That approach, published in June 1975, remains the basis for this first annual update.

The dual emphasis of this updated Plan is:

- The further refinement of priorities and strategic approaches identified in the initial National Plan for Energy RD&D
- The integration of the critical nontechnological aspects of energy development into RD&D consideration.

Technological Emphasis

The overall emphasis of this Plan is to support the private sector in the development and implementation of energy technologies that can begin to reduce the demand for oil and gas significantly in the balance of this century, and, where possible, in the near term.

To accomplish this, the Plan:

- Singles out conservation (energy efficiency) technologies for increased attention and ranks them with several supply technologies as being of the highest priority for national action
- Identifies six key supply technologies which can enter the market penetration phase in the near term
- Outlines initial program steps to overcome technological barriers to the rapid implementation of key technologies with near-term potential
- Adds a short-range planning category to focus attention on opportunities for technology development that may have effect within five years.

To balance these initiatives, the Plan also develops in further detail the longer-range programs given priority in ERDA's initial Plan.

Nontechnological Emphasis

The nontechnological emphasis of this Plan is to ensure that RD&D has taken account of all those factors which can facilitate the rapid integration of new energy technologies into the framework of the society.

To accomplish this, the Plan outlines approaches to:

- Government support to the private sector to accelerate market acceptance of key technologies after technological barriers to market penetration have been removed
- Integration of environmental planning at each stage in the process of technology development
- Interaction of public and private sectors at national, state, regional and local levels to ensure appropriateness of energy RD&D
- Development of a management process within ERDA to provide overall guidance and coordination of both technological and nontechnological aspects of energy development.

These approaches will be summarized and the basis for their emphasis will be explained in greater detail below.

The foundation of the National Plan is a set of recommended national energy technology goals, a strategy for achieving these goals, and a proposed set of national priorities for energy technology development.

To provide a basis for setting priorities in technology development and developing strategies for implementation, the Plan identifies eight national energy technology goals:

I. Expand the domestic supply and economically recoverable energy producing raw materials
II. Increase the use of essentially inexhaustible domestic energy resources
III. Efficiently transform fuel resources into more desirable forms
IV. Increase the efficiency and reliability of the processes used in energy conversion and delivery systems
V. Transform consumption patterns to improve energy use
VI. Increase end-use efficiency
VII. Protect and enhance the general health, safety, welfare and environment related to energy
VIII. Perform basic and supporting research and technical services related to energy

The Plan then develops a strategy for attaining these national goals:

NEAR TERM (Now to 1985 and beyond)	• Increase the efficiency of energy used in all sectors of the economy and extract more usable energy from waste materials • Preserve and expand major domestic energy systems: coal, light water reactors, and gas and oil from new sources and by enhanced recovery techniques.
MID TERM (1985 to 2000 and beyond)	• Accelerate the development of new process for producing synthetic fuels from coal and extracting oil from shale • Increase the use of fuel forms such as geothermal energy, solar energy for heating and cooling, and extraction of more usable energy from waste heat.
LONG TERM (Beyond 2000)	• Permit the use of the essentially inexhaustible resources: nuclear breeders; fusion; and solar electric energy from a variety of options including wind power, thermal and photovoltaic approaches, and ocean thermal gradients • Provide the technologies to use the new sources of energy, which may be distributed as electricity, hydrogen, or other forms throughout all sectors of the economy.

Initial ERDA analyses have led to the preliminary conclusions that only the successful development and implementation of a number of these technologies in a combination of approaches can provide adequate solutions to the present energy problem. All the national energy technology goals must therefore be pursued together. However this does not mean that every conceivable technology approach can or should be pursued with equal vigor or at all.

Although the proposed strategic approach is broad in scope, it recognizes the existence of limited resources, and consequently, the importance of setting priorities.

All appropriate technologies will be drawn upon to some extent in achieving the national technology goals. However, the development of some technologies is absolutely essential, while the development of others is more supportive and complementary. This distinction is based on six criteria:

- How substantial an energy contribution would successful development of the technology make possible?

Table I Technologies Now Available for Pursuing Major Energy Technology Goals

The last column of this table presents data from ERDA–48. It represents the maximum impact of the technology in any scenario measured in terms of additional oil which would have to be marketed if the technology were not implemented. Basis for the calculation is explained in Appendix B of ERDA—48. These data are being reexamined, and changes will be made when analysis is completed. In a number of cases, revised projections of impacts will be lower.

Technology	Term of Impact*	Direct Substitution For Oil & Gas**	RD&D Status	Impact in Year 2000 in Quads
GOAL I: Expand the Domestic Supply of Economically Recoverable Energy Producing Raw Materials				
Oil and Gas—Enhanced Recovery	Near	Yes	Pilot	13.6
Oil Shale	Mid	Yes	Study/Pilot	7.3
Geothermal	Mid	No	Lab/Pilot	3.1-5.6
GOAL II: Increase the Use of Essentially Inexhaustible Domestic Energy Resources				
Solar Electric	Long	No	Lab	2.1-4.2
Breeder Reactors	Long	No	Pilot/Demo	3.1
Fusion	Long	No	Lab	—
GOAL III: Efficiently Transform Fuel Resources Into More Desirable Forms				
Coal—Direct Utilization Utility/Industry	Near	Yes	Pilot/Demo	24.5
Waste Materials to Energy	Near	Yes	Comm	4.9
Gaseous & Liquid Fuels from Coal	Mid	Yes	Pilot/Demo	14.0
Fuels from Biomass	Long	Yes	Lab	1.4
GOAL IV: Increase the Efficiency and Reliability of the Processes Used in the Energy Conversion and Delivery Systems				
Nuclear Converter Reactors	Near	No	Demo/Comm	28.0
Electric Conversion Efficiency	Mid	No	Lab	2.6
Energy Storage	Mid	No	Lab	—
Electric Power Transmission and Distribution	Long	No	Lab	1.4
GOAL V: Transform Consumption Patterns to Improve Energy Utilization				
Solar Heat & Cooling	Mid	Yes	Pilot/Demo	5.9
Waste Heat Utilization	Mid	Yes	Study/Demo	4.9
Electric Transport	Long	Yes	Study/Lab	1.3
Hydrogen in Energy Systems	Long	Yes	Study	—
GOAL VI: Increase End-Use Efficiency				
Transportation Efficiency	Near	Yes	Study/Lab	9.0
Industrial Energy Efficiency	Near	Yes	Study/Comm	8.0
Conservation in Buildings and Consumer Products	Near	Yes	Study/Comm	7.1

* Near—now through 1985
Mid—1985 through 2000
Long—Post-2000
** Assumes no change in end-use device.

- In which time frame does the technology produce its initial energy impact?
- Does the energy output of the technology substitute directly for oil and gas supplies?
- What is the economic status and potential of the technology?
- What are the environmental and human health implications of the application of the technologies?
- What is the stage of development of the technology in the spectrum from the laboratory to the marketplace?

Table I summarizes the key characteristics of each technology with respect to some of these factors. These considerations and the strategic considerations discussed provide a basis for the priority ranking of the technology categories, listed in Table II.

Priority Ranking of Conservation Now Significantly Increased

Conservation (energy efficiency) technologies are singled out for increased attention and are now ranked with several supply technologies as being of the highest priority for national action. This ranking represents a major change from the initial Plan and reflects observations of only moderate progress to date on supply technologies, evaluation of public

Table II Proposed National Ranking of RD&D Technology Categories*

HIGHEST PRIORITY DEMAND	
NEAR-TERM CONSERVATION (EFFICIENCY) TECHNOLOGIES	• CONSERVATION IN BUILDINGS & CONSUMER PRODUCTS • INDUSTRIAL ENERGY EFFICIENCY • TRANSPORTATION EFFICIENCY • WASTE MATERIALS TO ENERGY
HIGHEST PRIORITY SUPPLY	
NEAR-TERM MAJOR ENERGY SYSTEMS	• COAL-DIRECT UTILIZATION IN UTILITY/INDUSTRY • NUCLEAR-CONVERTER REACTORS • OIL AND GAS ENHANCED RECOVERY
NEW SOURCES OF LIQUIDS AND GASES FOR THE MID TERM	• GASEOUS AND LIQUID FUELS FROM COAL • OIL SHALE
"INEXHAUSTIBLE" SOURCES FOR THE LONG TERM	• BREEDER REACTORS • FUSION • SOLAR ELECTRIC
OTHER IMPORTANT TECHNOLOGIES	
UNDER-USED (LIMITED APPLICATION) MID-TERM TECHNOLOGIES	• GEOTHERMAL • SOLAR HEATING AND COOLING • WASTE UTILIZATION
TECHNOLOGIES SUPPORTING INTENSIVE ELECTRIFICATION	• ELECTRIC CONVERSION EFFICIENCY • ELECTRIC POWER TRANSMISSION AND DISTRIBUTION • ELECTRIC TRANSPORT • ENERGY STORAGE
TECHNOLOGIES BEING EXPLORED FOR THE LONG TERM	• FUELS FROM BIOMASS • HYDROGEN IN ENERGY SYSTEMS

* Individual technologies are not ranked within the technology categories.

comment on the initial Plan, and further analysis of conservation opportunities. Specific reasons for assigning this higher priority to energy efficiency technologies are identified below.

Many of the technologies to improve energy efficiency currently appear to share one or more of the following characteristics:

- A barrel of oil saved can result in reduced imports.
- It typically costs less to save a barrel of oil than to produce one through the development of new technology.
- Energy conservation generally has a beneficial effect on the environment in comparison to energy produced and used.
- Capital requirements to increase energy use efficiency are generally lower than capital needs to produce an equivalent amount of energy from new sources since most new supply technologies are highly capital intensive.
- Conservation technologies can generally be implemented at a faster rate and with less government involvement in the near term than can new supply technologies.
- Energy efficiency actions can reduce the pressure for accelerated introduction of new supply technologies. Since the actions persist over time, the benefits are continuing.

These reasons deal generally with conservation technologies. The rate of application and introduction of conservation technologies in specific instances will be determined by the comparative economics and social acceptability of the available alternatives.

Because conservation technologies are characterized by their large number, their diversity, and the relatively small energy contribution of any one—in contrast to major supply technologies—a broad, general strategic approach is required to stimulate the market introduction and implementation of these more diverse technologies. Supportive of this approach, the new short-range planning category initiated in this Plan is particularly appropriate.

In addition to the near- (1985), mid- (1985-2000), and long-term (post-2000) planning horizons established by ERDA's enabling legislation, a new planning horizon—0 to 5 years—will be included in the National Plan for Energy RD&D. The 5-year forward focus is intended to roll forward each year,

and will be institutionalized and monitored for successes and failures.

While opportunities to be considered within this focus are sought throughout the entire ERDA program, and nuclear, fossil, and solar and other technical areas are being included, it is likely that the predominant opportunities will be identified within the conservation program. Opportunities for fuel substitution are also being sought because of their beneficial impact on oil imports and relief of gas shortages.

While technologies such as geothermal and solar heating and cooling are assigned only a moderate priority in the ranking, because of projected limitations in their application, both technologies can have an impact on the Nation's energy demand in the mid term if the institutional infrastructures to support their market penetration can be established. These technologies are important because they are sufficiently well developed to be employed on a regional basis when the resources can be exploited economically. The geothermal resources and technologies included in this category are limited to hydrothermal and geopressurized applications, and the solar heating and cooling technologies may be limited to areas that enjoy high levels of insolation and experience relatively high costs for alternative fuels.

The Plan and The Federal Energy RD&D Program

Federal budget allocations are designed to encourage and support private sector initiatives in energy RD&D; national energy technology priorities do not, therefore, translate directly to the ERDA energy budget for any one year for several reasons:

- Differences exist in the scope of effort and the extent of funding required at different phases in the maturing of energy technologies. In general, earlier research efforts require a lower level of funding than, say, demonstration phases.
- Many of the technologies will be developed in the private sector and the distribution of necessary effort between the private sector and the Federal Government will vary tremendously.
- The nature of government involvement may differ for different technologies. RD&D is only one mechanism for government involvement.
- Other government agencies also have responsibilities in energy RD&D. These are reflected in the total Federal budget and in ERDA's planning process, but do not appear in the ERDA budget.

The 1977 Federal budget and the Administration's legislative program provide strong support for energy RD&D. The total allocation for energy RD&D has been increased by more than 30 percent. The Federal budget for 1977 demonstrates the Administration's commitment to the importance of energy research, development, and demonstration as stressed in the Plan which was a key input to the President's budget process. In this year's budget, the amount earmarked for energy research, development, and demonstration represents a 30 percent increase in budget outlays over the previous year. Significant budget increases this year occur in many energy RD&D areas.

Among the specific budget decisions, the President has placed emphasis on closing the fuel cycle in the nuclear light, water reactor program by providing a substantial increase for management of nuclear waste and chemical reprocessing. The increased funding in nuclear waste management represents a recognition on the part of the Administration that safe and environmentally sound nuclear waste disposal, which is a responsibility of the Federal Government, should be demonstrated on an expedited basis. To encourage and enable private sector to build, own, and operate additional U.S. enrichment capacity, the Nuclear Fuel Assurance Act was proposed to Congress in June 1975. The Act will provide ERDA necessary authority to negotiate cooperative agreements with private firms which, after Congressional approval, would provide temporary financial assurances to these firms.

Conservation, recommended in the Plan for accelerated development, has also received an increase in FY 1977 over FY 1976 of 64 percent, or essentially a rate of increase two times the overall program average.

The budget also provides funds to initiate a synthetic fuel program in 1976 as an essential part of a national RD&D effort. Its purpose would be to provide assistance to the private sector to encourage the development of both conventional energy technology (e.g., fossil fuel and nuclear power plants) and emerging technologies (e.g., synthetic fuel from coal, oil shale, and other domestic resources).

Even with the energy conservation measures outlined in this Plan, the demand for oil and gas is expected to outstrip the combined domestic supply and the current level of imports. Moreover, the gap between demand and domestic production is widening.* Over the next 25 years, synthetic fuels offer a domestic energy alternative to imported oil and natural gas.

A program of legislative, budgetary, and administrative actions to undertake a Federally supported synthetic fuels initiative was considered by Congress in the fall of 1975 and, although the program was not authorized during that session, the 1977 Budget provides funds to implement during 1976, a $2 billion loan guarantee program in ERDA. With the

* This relationship is graphically portrayed in Figure III-3.

enactment of EIA, this program would be transferred to EIA and expanded from $2 to $6 billion in loan guarantees, to meet the current 1985 objectives of 350,000 barrels of oil per day of synthetic fuel production capacity.

In Tables III, IV and V, growth of Federal energy RD&D programs is depicted. Table III lists budget outlays of all Federal agencies performing RD&D and Tables IV and V show ERDA budget amounts. Figure III illustrates percentage increases in ERDA's major program areas.

Volume II of this Plan (published separately) describes in detail the Federal programs for development of the technologies.

Table III Federal Energy R&D (in millions)

	FY 75		FY 76*		FY 77	
	BA	BO	BA	BO	BA	BO
Direct Energy R&D						
ERDA	$1,317.0	$1,011.0	$1,657.0	$1,427.0	$2,435.0	$2,009.0
DOI	89.9	54.2	104.0	93.3	98.3	96.3
EPA	80.8	18.2	56.8	76.6	55.4	76.6
NRC	58.9	51.7	87.5	76.9	104.0	98.2
NASA	0.8	0.8	1.7	1.0	–0–	0.8
Subtotal	1,547.4	1,135.9	1,907.0	1,674.8	2,692.7	2,280.9
Supporting R&D						
ERDA	362.0	313.0	403.0	373.0	430.0	404.0
DOI	33.2	30.9	59.0	56.7	66.8	65.2
EPA	53.2	5.0	43.2	43.4	41.6	43.4
NRC	2.3	2.1	9.6	9.1	5.3	5.0
NSF	103.2	65.9	114.6	74.2	123.4	106.9
Subtotal	553.9	416.9	629.4	556.4	667.1	624.5
Total Federal Energy R&D	$2,101.3	$1,551.9	$2,536.4	$2,231.2	$3,359.8	$2,905.4

* Funds for FY 76 Transition Quarter are not included.

Table IV ERDA Energy R&D Budget (Outlays in millions)

	FY 75	FY 76†	FY 77	FY 76 to FY 77 percent change*
Direct Energy R&D				
Nuclear Fuel Cycle and Safeguards	$ 120	$ 163	$ 282	73
Conservation	21	55	91	64
Geothermal	21	32	50	57
Fusion	151	224	304	36
Fission	538	522	709	36
Solar	15	86	116	35
Fossil	138	333	442	33
Environmental Control Tech.	7	12	15	24
Subtotal	1,011	1,427	2,009	
Supporting Research				
Basic Energy Sciences	165	188	205	9
Environmental Research	148	185	199	7
Subtotal	313	373	404	
Total ERDA Energy RD&D	$1,324	$1,800	$2,413	

† Funds for FY 76 Transition Quarter are not included.
* Percentage change calculated prior to rounding outlays.

Table V ERDA Energy R&D Budget (Authority in millions)

	FY 75	FY 76†	FY 77	FY 76 to FY 77 percent change*
Energy RD&D Programs				
Nuclear Fuel Cycle and Safeguards	$ 118	$ 173	$ 347	101
Conservation	36	75	120	60
Geothermal	28	31	100**	223
Fusion	183	250	392	57
Fission	567	602	823	37
Solar	42	115	160	39
Fossil	335	398	477	20
Environmental Control Tech.	8	13	16	23
Subtotal	1,317	1,657	2,435	
Supporting Research				
Basic Energy Sciences	191	210	227	8
Environmental Research	171	193	203	5
Subtotal	362	403	430	
Total ERDA Energy RD&D	$1,679	$2,060	$2,865	

† Funds for FY 76 Transitional Quarter are not included.
* Percentage change calculated prior to rounding authority.
** Includes $50 Million for Geothermal Loan Guarantee Program.

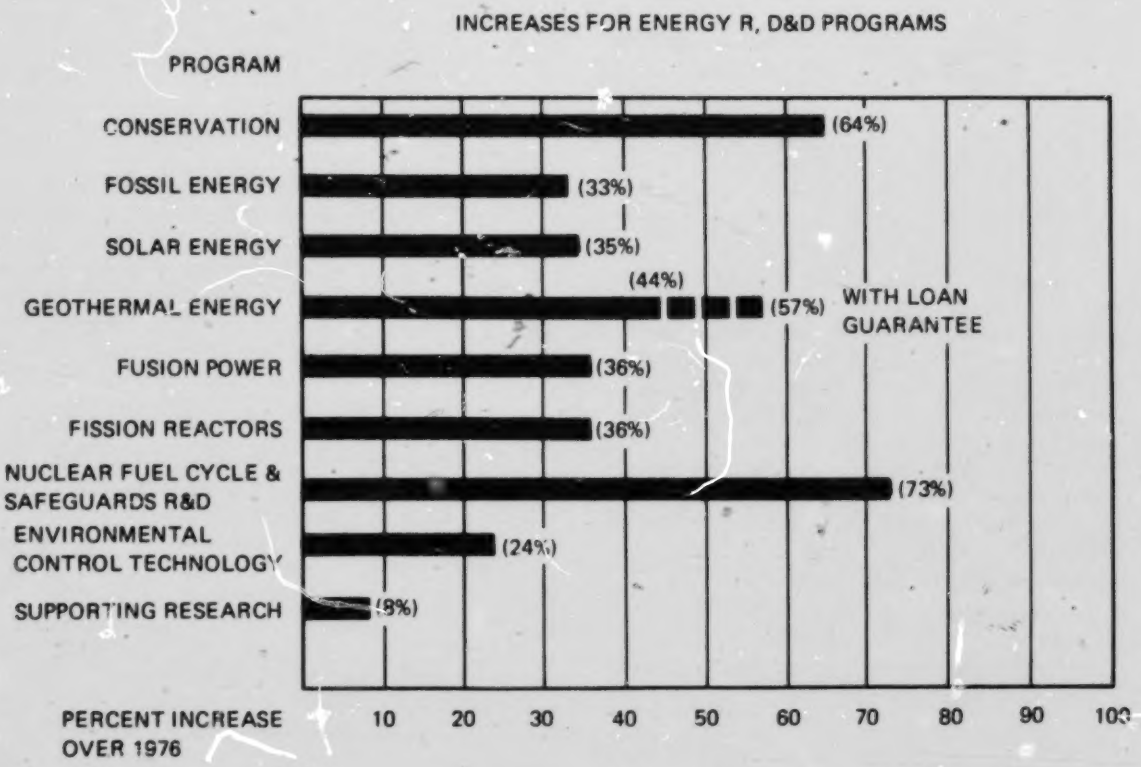


Figure III Energy Research and Development Administration FY 1977 Budget

This Plan focuses on a set of technologies (involving both supply and demand) and a related set of operational approaches. If successfully pursued, these approaches could result in significant market penetration of technologies that could ease the overall energy problem within the next critical decade.

The Plan therefore identifies seven high-priority technologies that have the potential for making significant energy contributions in the near term and mid term. They are:

- Conservation (energy efficiency)
- Light water reactors
- Enhanced oil and gas recovery
- Direct utilization of coal
- Synthetic fuels
- Geothermal energy
- Solar heating and cooling

The Plan develops a preliminary strategic approach for each, analyzing its marketability and a strategic approach to support its commercialization by the private sector.

The Plan also identifies strategies for the development of three high-priority programs with longer-term potential:

- Breeder reactors
- Solar electric
- Fusion

To be effective in supporting the private sector in the development and commercialization of energy technologies, the Federal Government must take the lead in helping to create mechanisms for interaction between ERDA and other public and private sector groups. Introduction of new energy technologies will directly or indirectly touch all Americans and all private institutions, and will require the concrete action of all—Congress, Federal Government agencies, state and local governments and regional groups, and the private sector.

An important operational element of the Plan, therefore, is to ensure the participation of each of these groups and to promote interaction among them, so that RD&D program planning can be responsive to the international, national, regional, and local objectives. To this end, the Plan outlines initiatives designed to:

- Promote and support cooperative international efforts to develop solutions to common energy problems

- Improve interaction among Federal agencies involved in energy RD&D
- Strengthen interfaces between ERDA and industry, state and local governments, universities, and the public
- Capitalize on ERDA's existing regional structure to coordinate research, development and demonstration of energy technology with local economic, environmental, and social concerns.

ERDA is developing an internal management system for analysis, resource allocation, implementation, and evaluation of its programs to ensure the most effort to complement the private sector in meeting national energy goals. The implementation of this system will take time, will be difficult, and will require the assistance of the private sector. It is vital that ERDA develop a well-coordinated and integrated system for program planning, budgeting, and review (PPBR system). Such a system is needed to provide a framework for:

- Analyzing the Nation's energy needs
- Formulating Federal plans for addressing those needs.
- Designing programs to carry out specific objectives.
- Allocating resources consistent with the Plan and programs
- Ensuring that the programs are effectively designed and managed.

For example, it is necessary in developing an energy plan to be able to determine which technologies are likely to be developed by the private sector with minimal government involvement and which will require more specific government assistance. To make these projections, planners must be familiar with industry criteria for market penetration and must be able to anticipate probable private sector behavior in terms of investor and consumer acceptance of new technology. If a technology is judged to be a poor commercial risk in the private sector, a judgment must be made as to whether the potential public benefits are sufficient to justify a government role. Inputs to determine this must come from interaction with industry and with the public (e.g., consumers, local and regional entities, environmental groups). This logic is presented in Figure IV.

Through the use of PPBR, the current process of establishing priorities among technologies in the Plan can be vastly improved. The PPBR system is being designed to develop an energy system option which can evaluate public and private rates of return and develop measures of relative value among technology programs.

It is anticipated that for each technology program, the system will develop five basic documents:

1. **Program Strategy:** This document will explore the need, if any, for a Federal role and the effectiveness of RD&D and other potential programmatic solutions as illustrated by Figure II. It will present a program strategy and establish the major goals and milestones for the program.
2. **Program Plan:** The program plan will chart the detailed course of the program, typically over a several-year period leading to a major programmatic decision (e.g., should a demonstration phase be undertaken?). The basis for the program plan is the program strategy, but the plan would be more specific in assigning program responsibility and developing management structure and will seek to define the most cost-effective Federal program to achieve the agreed objectives.
3. **Environmental Development Plan:** The plan for environmental development will be a companion document to the program plan, detailing the program of environmental research that must parallel technology development. Environmental issues involved in developing the technology are identified and a program outlined for resolving these issues in a time period consistent with the rate of technology RD&D.
4. **Program Approval Document:** This is an internal ERDA document that will present in some detail the activities to be conducted and milestones to be achieved within approved budgets for a given fiscal year. Its purpose is to provide a baseline for monitoring program operations.
5. **Environmental Impact Statement (EIS):** Within the structure of the National Environmental Policy Act, ERDA intends to use the EIS as a major input to decision processes. Where required, an EIS will be prepared to illuminate a major "go/no go" program decision. It summarizes the information developed by the Environmental Development Plan and uses it to address the issues raised. In this way, ERDA hopes that these issues can be identified at the start of an appropriate program phase, so that they can be systematically addressed.

Developing the Plan

Because the nature of the energy problem is dynamic, the annual revisions of this Plan can be expected to evolve in response to changes and to new information.

The National Plan for Energy RD&D is required to be updated annually to remain responsive to continuous changes in the external environment, both with regard to energy and non-energy events and policies. Technical and nontechnical

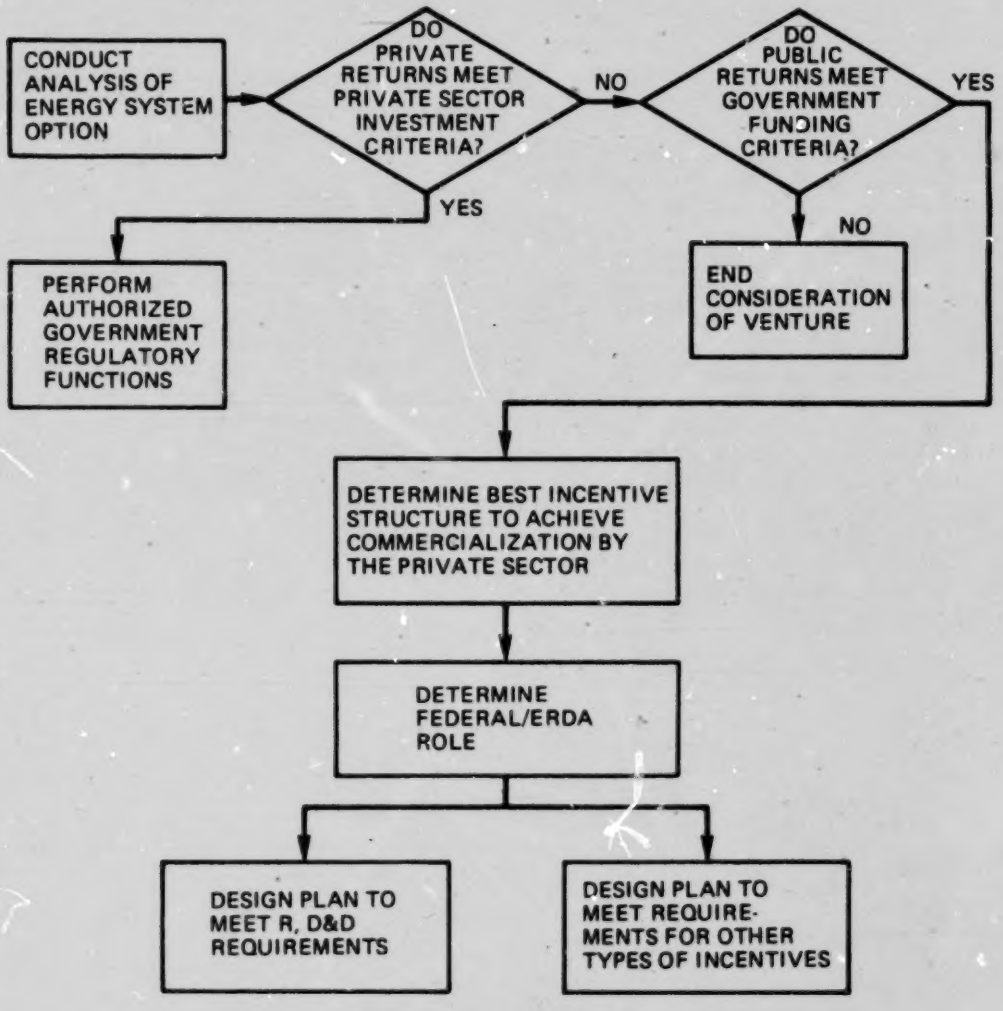

CONDUCT ANALYSIS OF ENERGY SYSTEM OPTION
DO PRIVATE RETURNS MEET PRIVATE SECTOR INVESTMENT CRITERIA?
NO
DO PUBLIC RETURNS MEET GOVERNMENT FUNDING CRITERIA?
YES
YES
NO
PERFORM AUTHORIZED GOVERNMENT REGULATORY FUNCTIONS
END CONSIDERATION OF VENTURE
DETERMINE BEST INCENTIVE STRUCTURE TO ACHIEVE COMMERCIALIZATION BY THE PRIVATE SECTOR
DETERMINE FEDERAL/ERDA ROLE
DESIGN PLAN TO MEET R, D&D REQUIREMENTS
DESIGN PLAN TO MEET REQUIREMENTS FOR OTHER TYPES OF INCENTIVES

Figure IV Strategic Planning Logic

factors which constitute these changes and influence the evolution of this Plan can be characterized as:

- Assessments of international and domestic events and their effect on the Plan
- Assessments of the National Plan for Energy RD&D based on the viewpoints and insights of others
- Assessments of the results of energy systems analysis studies and their effect on the Plan
- Assessment of RD&D activities in the private sector.

An integral part of this Plan is a detailed program for improving the informational base for these assessments, facilitating ERDA's access to this information, and developing the tools to better analyze the implications of new energy technologies in terms of economic growth, environmental impact, and public policy.

Decisions on the adequacy of energy RD&D programs are being continually refined on the basis of improved analyses and evaluation mechanisms being developed within ERDA.

Successful implementation of new energy technologies will produce changes in the underlying economic and institutional systems of this country. To provide information to the public as a basis for wise

energy choices, analyses of energy systems attempt to identify these changes and assess their potential impacts.

This update draws from preliminary conclusions from three selected areas of analysis aimed at:

- Understanding the relationships among energy, economic growth, and environmental impact as a result of the introduction of new energy technologies and other energy policy initiatives
- Calculating the net energy aspects of energy technologies
- Supporting market penetration initiatives through specific market studies (e.g., the Electric Utility Study mentioned in Chapter VI).

Most of these studies are not yet complete. It appears, however, that they will be useful in selecting promising energy technologies and in clarifying the degree of Federal participation—if any—required to develop and introduce new technologies. Analyses to date do not yet suggest the need for a sharp revision in the basic goals and strategies in this Plan.

Although it is too early to state with certainty what will be included in future reports, the results of three efforts essential to ERDA's own planning will probably be included and help to shape the next annual Plan.

These activities are:

- Developing benefits and costs of energy RD&D
- Establishing priorities for component programs
- Analyzing energy RD&D activities in the private sector.

During 1976, it is ERDA's goal to apply the tools of energy systems analysis to the quantification of costs and benefits of selected energy technologies and to report on this work in the next Plan.

Using its developing PPBR system, ERDA expects in the coming year to be able to extend the process of priority-setting to a much greater level of detail than is presently possible. The PPBR can make program priorities and the bases for resource allocations more explicit which, in turn, will help to delineate the implications of various alternatives.

Finally, as an essential means to reinforce and support private sector activities, it is ERDA's goal to initiate an analysis of ongoing and anticipated RD&D efforts in the private sector and to provide an interim report in the 1977 Plan.

Chapter I—The National Energy Problem and the Nature of Its Solution

The United States is a nation rich in domestic energy resources, yet depends on the importation of large quantities of fossil fuels. This is the essential paradox of the Nation's energy problem.

Today, over 75 percent of the Nation's energy demand is filled by petroleum and natural gas. These energy resources are in dwindling supply domestically and, ultimately, worldwide. Indeed, domestic production of these fuels has declined since the embargo of October 1973. On the other hand, coal, the most abundant domestic fossil fuel, supplies less than 20 percent of current energy needs, uranium provides only about 2 percent of the Nation's energy, and alternative sources such as solar or geothermal energy provide little or no energy. Clearly, the Nation relies most on the least plentiful domestic energy resources and least on the most abundant resources.

The present level of petroleum and natural gas use reflects their relative cost and abundance in the past. As a result, this Nation has not sought, until recently, as a matter of national policy either to explicitly limit the rate of energy growth or to develop an adequate range of readily available alternative energy supply systems for the future. Instead, the Nation has built up over the last half century a large infrastructure based on the production and use of petroleum and natural gas. The cost of this infrastructure exceeded $150 billion, and the Nation cannot afford to loose the value of this investment.

As a result of reliance on petroleum and natural gas and of the continuing decline of domestic production, the proportion of energy needs met by imports has remained at approximately 20 percent since the oil embargo, even despite the decreases in U.S. energy demand associated with the recent recession. The annual cost of this imported energy has risen from about $3 billion in 1970 to about $27 billion today. The difference in cost is mostly attributable to increases in price rather than absolute levels of imports. Most critically, foreign sources of these energy supplies have become less certain. Canada has restricted its exports to the U.S.; the Organization of Petroleum Exporting Countries (OPEC) cartel has exhibited cohesion and purpose in controlling prices and production in the face of weakened world demand; and the Middle East remains politically unstable.

But even if none of these things had happened, the long-term problem of a diminishing petroleum and natural gas resource base, both domestic and worldwide, remains. As standards of living increase throughout the world, the demand for petroleum and natural gas will increase for many countries. But the resource base will continue to decrease. The events of the last few years have served, importantly, to dramatize the resource problem. They create serious present difficulties, but they are only short-term manifestations of the longer term problem.

Solving the energy problem requires broadening the base of domestic energy resources and adapting to the new resource base more quickly than ever before.

A variety of domestic energy resources should be developed because it would reduce our excessive reliance on one form of energy—a reliance that has at times severely constrained national policy—and because social choice is likely to be best served by a range of energy choices. It is not possible to predict what the Nation's interests and its people's desired life style will be at the end of this century. But whatever those interests and desires are, a sufficient supply of affordable energy should be available to serve them. The social decisions on which technologies will be chosen for implementation and on the degree to which they will be employed can best be made if alternative energy forms are available.

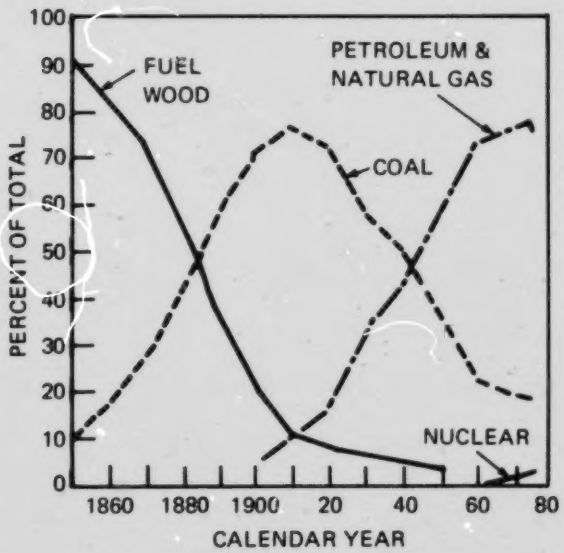
The urgency of solution should also be stressed. Historical perspectives (Figure I-1) show that in the past it has taken about 60 years to move from reliance on one major energy resource to reliance on another. Domestic production of petroleum and nat-

ural gas now appears to have reached or passed its peak. The relative domestic market shares of these two energy supplies are expected to decrease with time. A transition to new energy resource bases must be accomplished, but this transition from dependence on a narrow base of diminishing resources to reliance on a broader range of less limited or unlimited alternatives must be made more swiftly than ever before. The Nation does not have 60 years this time if growth in the energy sector is to be supported without undue reliance on foreign energy sources.

An aggressive national program of technological development can expedite this process because broadening the domestic energy resource base requires rapid expanded utilization of existing and new technology. Technology for using some resources other than oil and gas, such as coal and nuclear, is already available. Nevertheless, these technologies often require economic, environmental, and technical improvements. Furthermore, longer term solutions to the energy problem, which involve the ability to exploit very large or nearly inexhaustible domestic resources, require specific technological advances that are still decades from large-scale utilization.

But improving existing technologies and developing attractive new ones require substantial investments—investments that must be made in a climate of uncertainty. Today there are uncertainties about future energy demand; the relative economics of energy technologies; the interplay with the environment; the final choice of energy systems; the date of introduction or the rate of implementation of a particular energy technology; developments that might impact on the worldwide energy problem; and other factors that affect the solution to the domestic energy problem.

Despite these uncertainties, decisions must be made today, without foreclosing future options, even though important information may be unavailable or analyses may be incomplete. Functioning effectively in this environment necessitates continuous feedback and readjustments which are necessary elements of planning under conditions of uncertainty.



SOURCE: HISTORICAL STATISTICS OF THE UNITED STATES BUREAU OF THE CENSUS; U.S. BUREAU OF MINES, 1974

Figure I–1 U.S. Energy Consumption Patterns

The Role of the Private and Public Sectors

With few exceptions, the private sector is the main producer and consumer of energy. The role of the private sector is therefore paramount in the accelerated introduction of energy technology, and thus to the solution of the Nation's energy problem.

Specifically, the private sector is prepared to take risks, has the inherent flexibility to act, controls the preponderant share of new investment funds, and possesses the necessary managerial capabilities for carrying out most of the RD&D and virtually all of technology introduction. Moreover, market forces as they are perceived by decision-makers in the private sector will determine the economically optimum mix of alternative energy technologies to displace the undue reliance on petroleum and natural gas. **Thus, an important theme of this report is that the private sector and market forces are the most efficient means of achieving the Nation's energy goals.**

The role of the public sector, especially that of the Federal Government, is therefore supplementary —to do what cannot otherwise be done privately. The Federal role, in turn, divides into three parts. Government can establish an appropriate policy climate for private sector action, share risks with the private sector, and conduct a complementary RD&D program. Of course, all three may be required to introduce any single technology.

Establishing an Appropriate Climate

The preferred role of government is to establish an appropriate policy climate for technology introduction. In a few situations—notably uranium enrichment—the government is the sole commercial agent because of earlier activities growing out of its national security responsibilities. Current government initiatives in uranium enrichment would decrease the government's control and contribute to commercialization efforts by the private sector. In other situations, the government's regulatory role greatly affects the introduction of technologies. For example, changed government price regulations on oil and gas

could make conservation technologies and more expensive enhanced-recovery techniques for oil and gas more attractive. Similarly, changing regulation of nuclear plants and other major installations could speed construction and lower the cost of the technologies. Such activities need to be continually assessed to ensure that a proper balance is maintained among various governmental objectives.

Other examples of government roles that can stimulate or inhibit private action are energy pricing policy and strategic storage (Federal Energy Administration); energy regulation (Federal Power Commission); investment tax credit (Department of the Treasury); environmental regulation (Environmental Protection Agency); Federally owned resource management (Department of the Interior); and siting standards (state and local governments).

In general, then, the preferred role for government is to establish an appropriate climate for private introduction of energy technology by:

- **Providing leadership and assistance:** Establishing a consistent energy policy and regulatory network
- **Managing energy resources located in Federal lands:** Making these resources available for use over time with due regard to environmental, aesthetic, conservation, land use, or other factors of national interest
- **Establishing and enforcing economic and antitrust regulation:** Making energy decisions consistent with national economic goals; providing energy to the American consumer at the lowest possible cost consistent with the need for secure energy supplies; assisting the development of standards, criteria, and certification procedures
- **Protecting human health and the environment:** Ensuring the protection of the Nation's environment and the public's health and safety
- **Coordinating Federal policy with international policy:** Coordinating the Nation's energy policies with those of other consuming and producing nations to promote interdependence as well as independence.

Sharing Risks

Even with a regulatory and policy climate more conducive to private investment, private action may fail to follow because risks remain excessive. Both technological uncertainty and the difficulty of projecting future economic conditions contribute to excessive risk, even when technical feasibility is known.

In these cases, government can stimulate private-sector action by sharing risks—that is, by absorbing the greater-than-commercially-acceptable risk of investing in energy technology.*

This relatively new government role has the advantage of producing a self-liquidating government interest in successful projects. It is a technique contemplated by the Federal Nonnuclear Energy Research and Development Act** and by other legislation administered by ERDA and other agencies.

At least four specific risk-sharing ventures are already in place or in the formative stage:

- The proposed Nuclear Fuel Assurance Act, designed to move a hitherto Government monopoly in uranium enrichment production into the private sector by temporary financial assurance to private enrichment firms
- The proposed synthetic fuels commercial demonstration program, aimed at constructing a first round of commercial-scale synthetic fuel plants (ERDA)
- The geothermal loan guarantee program,*** which will assist both RD&D and introduction of new geothermal technology (ERDA)
- The loan program to open new coal mines**** (FEA)

Beyond these specific ventures, the President has proposed the Energy Independence Authority (EIA). The EIA would have at its disposal a variety of tools to share the risks on many types of energy projects.

Conducting RD&D

Increasingly, RD&D is required to develop new technology that can subsequently be introduced to develop new domestic energy resources, or to exploit old resources more cleanly and safely. Much of this kind of RD&D is already being carried out by the private sector. But the private sector cannot conduct **all** the necessary RD&D; Federal help is necessary. However, a Federal RD&D program should neither act as a substitute for private funds nor invest too heavily in speculative projects that may never capture a place in the market.

The choice is difficult, but the Federal Nonnuclear Energy Research and Development Act† of 1974, one of the acts that establishes the basis for ERDA's programs, addresses this question. The relevant text states:

> "In determining the appropriateness of Federal involvement in any particular research and development undertaking, the Administrator shall give consideration to the extent to which the proposed undertaking satisfies criteria including, but not limited to, the following:
>
> (A) "The urgency of public need for the potential results of the research, development, or

* See Chapter V for a discussion of the criteria for government investment.

** Public Law 93–577, Section 7.

*** Title 2, Public Law 93–410, "Geothermal Energy Research, Development and Demonstration Act of 1974."

**** Public Law 94–163 "Energy Policy and Conservation Act."

† Public Law 93–577, Section 5(b)(2).

demonstration effort is high, and it is unlikely that similar results would be achieved in a timely manner in the absence of Federal assistance.

(B) "The potential opportunities for non-Federal interests to recapture the investment in the undertaking through the normal commercial utilization of proprietary knowledge appear inadequate to encourage timely results.

(C) "The extent of the problems treated and the objectives sought by the undertaking are national or widespread in their significance.

(D) "There are limited opportunities to induce non-Federal support of the undertaking through regulatory actions, end-use controls, tax and price incentives, public education, or other alternatives to direct Federal financial assistance.

(E) "The degree of risk of loss of investment inherent in the research is high, and the availability or risk capital to the non-Federal entities which might otherwise engage in the field of the research is inadequate for the timely development of the technology.

(F) "The magnitude of the investment appears to exceed the financial capabilities of potential non-Federal participants in the research to support effective efforts."

This legislative mandate fits closely with the nature of the technology-introduction problem discussed in this chapter. Sections (A) and (B) of the Act recognize the urgency of obtaining the results of RD&D—an urgency that may mandate government involvement. Similarly, Section (C) stresses the importance of the national benefits to be obtained and recognizes that local efforts may not produce them. Coal and nuclear energy are good examples of nationally important energy sources that may not be able to be tapped fully by local or regional efforts. Section (F) notes that some energy technology development is just too expensive for the private sector; fusion power illustrates this case.

At the same time, the Act infers that other avenues should be explored before deciding on direct Federal involvement. Section (D) suggests that obstacles to private action should first be removed, and Section (E) recognizes the potential value of risk-sharing.

The Role of Federal Agencies

When government needs to play any of its three roles, it requires the action of numerous Federal agencies:

- Various Federal agencies are responsible for recommending comprehensive national energy policy that is in balance with other national policies and priorities. Among these agencies are:
  - —Energy Resources Council
  - —Council of Economic Advisers
  - —Council on Environmental Quality
  - —Domestic Council
  - —Water Resources Council
  - —Federal Energy Administration.
- Various Federal agencies are directly involved in managing the expenditures of energy or related RD&D resources. Among these agencies are:
  - —Energy Research and Development Administration
  - —Department of the Interior
  - —Environmental Protection Agency
  - —Nuclear Regulatory Commission
  - —National Science Foundation
  - —National Aeronautics and Space Administration.
- Several agencies are involved in the regulatory aspects of environmental protection and human health and safety. Chief among these are:
  - —Environmental Protection Agency
  - —National Institute of Environmental Health Sciences
  - —National Institute for Occupational Safety and Health
  - —Department of Labor (Occupational Safety and Health Administration)
  - —Occupational Safety and Health Review Commission.
- Other agencies are involved in setting standards and regulations for energy-related organizations. Among these are:
  - —Federal Energy Administration
  - —Federal Power Commission
  - —Nuclear Regulatory Commission
  - —Department of Commerce (National Bureau of Standards)
  - —Department of Transportation
  - —Federal Trade Commission
  - —Interstate Commerce Commission
  - —Federal Maritime Commission.
- Other agencies work with the private sector to assist the market penetration of key energy technologies. Among these are:
  - —Department of Housing and Urban Development
  - —Department of Commerce
  - —Department of the Interior
  - —Small Business Administration
  - —Department of Transportation
  - —General Services Administration.
- Finally, there are agencies that deal with other areas that have direct energy implications. Among these are:
  - —Department of State
  - —Department of the Treasury

—Department of Defense
—Department of Health, Education and Welfare.

The Role of ERDA

Energy RD&D is an important component of the total Federal role, and ERDA plays a leadership role here in three ways.

First, ERDA develops and updates this Plan. The Plan cannot, and is not intended to, represent technology as the total solution to the energy problems, predict certain success for any particular program, ensure immediate results, or preselect a single energy future. Rather, the Plan performs three principal functions:

1. Establishes a likely order of technology introduction from the near- to the long-term, and identifies current major guideposts for measuring and assessing* the rate of technology introduction. These guideposts can be useful in evaluating whether enough new technologies are being introduced to solve the Nation's energy problem, and in identifying possible compensatory government action.
2. Proposes energy RD&D priorities linked directly to the order of technology introduction. These national priorities are intended to be generally helpful in evaluating the national energy RD&D effort. In particular, the priorities bear on the allocation of government RD&D resources.
3. Stimulates debate on the technology options open to the Nation in the context of the total energy problem. ERDA believes this context, which forces the weighing of all alternatives together, facilitates the objective evaluation of individual technologies. It is a debate that should be encouraged.

Second, ERDA is responsible for monitoring and reporting on the entire Federal energy RD&D effort. In this way, a coordinated program aimed at common objectives is more likely to emerge. Volume II of this Plan summarizes the activities of 23 Federal agencies as they relate to the total RD&D program.

Finally, ERDA is the principal sponsor of Federal energy RD&D as well as of several risk-sharing programs.

This chapter has examined the energy problem and the nature of its solution, a sketch not so very different from that drawn in ERDA-48. More importantly, it has attempted to set forth the institutional structure in which the energy problem must be solved. Specifically, it has spelled out the division of responsibility between the private and the public sectors, as well as the three supportive roles played by the Federal Government. Similarly, the functions of the several Federal agencies, and especially ERDA, have been clarified, and the cooperation of the Federal energy RD&D program has been emphasized. However, a discussion of the crucial role to be played by state and local governments has been postponed until Chapter IV to simplify this discussion.

---

* These assessments, which will be regularly included in subsequent editions of this document, are based on:
- How much domestic oil and gas is actually found and produced
- The availability of imports from secure sources, plus the backup protection against supply disruption that can be gained from stockpiling
- The degree and rate of implementation of both existing and emerging technologies
- The degree of modification of life styles the Nation finally adopts
- The degree of end-use efficiencies that may finally be attained
- The level of effort that can be allocated to the development of new technology by the public and private sectors
- The economic and technical success finally achieved by new technologies
- The extent of environmental, economic, and sociopolitical considerations.

Chapter VI discusses such assessments more fully.

THE PLAN

Chapter II—Fundamentals of the Plan

The National Plan for Energy Research, Development and Demonstration has been formulated as an integral part of the overall policy for addressing the Nation's energy needs. It is responsive to the national energy policy goals and principles enunciated by the President (see Preface). While its emphasis is on technological development, it is consistent with and reflects broader policy concerning import levels, foreign relations, the needs of industry and consumers, fiscal policy, environmental protection, and human health and safety.

This chapter presents the fundamentals of the National Plan for Energy RD&D:

- National policy goals related to energy
- National energy technology goals
- Strategy and priorities for RD&D.

In addition, the final section of the chapter discusses specific supporting technologies, basic energy science, and environmental research.

National Policy Goals Related to Energy

The National Plan for Energy RD&D is based on five national goals formulated to guide the introduction of new technology:

- Maintain the security and policy independence of the Nation
- Maintain a strong and healthy economy, providing adequate opportunities and allowing fulfillment of economic aspirations (especially in the less affluent parts of the population)
- Provide for future needs so that future life styles remain a matter of choice and are not limited by the unavailability of energy
- Contribute to world stability through cooperative international efforts in the energy sphere
- Protect and improve the Nation's environmental quality by assuring that the preservation of land, water, and air resources is given high priority.

These goals express ERDA's current understanding of the national interest with respect to energy technology, and should therefore serve as the basis for energy RD&D in both the private and public sectors. Because of their fundamental importance, these goals merit continued scrutiny and debate.

The Need for Choices

To achieve the national policy goals related to energy, the U.S. must have the flexibility of a broad range of energy choices.

It is not possible to predict now what our Nation's interests and its people's desired life style will be at the end of this century. Whatever those interests and desires are, however, energy should be available to serve them. The present situation, in which national policy and social choice are constrained by overreliance on increasingly scarce forms of energy, cannot be allowed to recur.

It would be presumptuous now for the Nation to select a single technological course of action toward long-term energy independence. The successful exploitation of new energy sources and the reduction of the growth rate of energy demand require a broad range of approaches. Central among these is the development and deployment of new technology; that is the focus of this Plan. Because technology development is uncertain, commitment now to one set of technologies for the future would ignore the possibility of failure. Even if technological success were guaranteed, it would be impossible to ensure that the resulting technology would be best suited for future conditions.

Finally, it is reasonably certain that the Nation would be better served by leaving to the future the ultimate choices of how much energy is consumed, which technologies are actually implemented, and to what degree. To provide limited options for the future would undermine the strengths of the market place and individual choices of life style.

Responding to the Problem

In its immediate response to the energy situation, the Nation is currently limited to two choices: importing more oil and natural gas or making do with less energy. Successful achievement of national goals, however, mandates a more positive policy aimed at exploitation of domestic resources and reduction of unnecessary waste in energy consumption.

The Nation has several possible courses of technological development that can assist in solving the energy problem. The first course of action is to

produce more of the major fuels in use today. Secondly, new technologies to expedite the transition to resources that are presently under-used (e.g., solar energy for heating, geothermal) or essentially inexhaustible (e.g., fertile uranium for breeding, fusion fuels, solar energy for electrical generation) can be developed and introduced. Thirdly, to make better use of more plentiful resources, actions can be taken to alter present patterns of end-use consumption. These actions can facilitate the shift of major end-use sectors from dependence on scarce fuels to more plentiful resources. As an example, electrification of land transportation would terminate present dependence on oil and gas and allow needs to be met by any of the basic resources, all of which can be used to generate electricity. Finally, efficiency improvements can be made both in the conversion of resources into energy and in the end-use devices that use this energy to meet societal needs.

All these desirable courses of action, if they are to achieve their full potential, require the development and implementation of new or improved technology.

National Energy Technology Goals

The framework for organizing a National Plan for energy RD&D must be established in relation to the five national policy goals and must permit a positive response to the energy problem. To provide this framework, the four courses of technological development discussed above have been expanded into a set of national technology goals. Two additional goals have been added to cover activities that support all technological approaches. The set of national energy technology goals is as follows:

I. Expand the domestic supply of economically recoverable energy-producing raw materials
II. Increase the use of essentially inexhaustible domestic energy resources
III. Efficiently transform fuel resources into more desirable forms
IV. Increase the efficiency and reliability of the processes used in energy conversion and delivery systems
V. Transform consumption patterns to improve energy use
VI. Increase end-use efficiency
VII. Protect and enhance the general health, safety, welfare, and environment related to energy
VIII. Perform basic and supporting research and technical services related to energy.

These goals emphasize not only the development of technologies related directly to the energy supply, but also the development of technologies that focus on the:

- Crucial importance of reducing energy waste and increasing the efficiency of energy use in all sectors of the economy through the application of existing and new technologies
- Major role of technologies in protecting and enhancing the quality of the human and physical environment, a concept that must be fully integrated into all aspects of energy production and use
- Need for basic research and technology transfers from other high-technology areas to support and stimulate continuing innovation in the energy technology area.

The supply and demand technologies related to goals I through VI are listed in Table II-1. The table also shows the best estimates (developed last year) of the energy impact in the year 2000 of an aggressive but potentially attainable rate of introduction of each technology, and indicates the time frame in which each technology would begin to have an impact. This table summarizes the current spectrum of technology options from which the Nation may select and introduce new energy technology if economic and other criterias are met. Before a strategy for achieving these goals can be developed, however, it is necessary to examine the Nation's energy resource base—the resources presently available to address the Nation's energy problem.

The Importance of Resources

A crucial requirement in the development of a National Plan for Energy RD&D is an understanding of the Nation's energy resource base. That understanding must begin with knowledge of those resources currently in widespread use and known to exist, and those currently unused or under used. Despite the great visibility of new and exotic energy forms in both general and technical literature, the fact remains that the U.S. currently depends on coal, petroleum gases and liquids, hydroelectricity, and nuclear power to meet 99 percent of its energy needs. More critically, 75 percent of these needs are met solely by petroleum and natural gas, both of which are in limited domestic supply.

The following discussion of the Nation's resources will develop and illustrate two key points:

- The Nation possesses very large domestic fuels resources that are under-used or not used at all.
- The magnitude of the recoverable resources and, in many cases, even their availability are dependent upon technology.

Reliance on a Narrow and Declining Resource Base

The urgency of the need for transition to new energy sources emerges clearly from the intensive reappraisal of the Nation's oil and gas resources performed by the United States Geological Survey (USGS) and independently supported in a study by the National Academy of Science (NAS). These esti-

Table II–1 Technologies Now Available for Pursuing Major Energy Technology Goals

The last column of this table presents data from ERDA–48. It represents the maximum impact of the technology in any scenario measured in terms of additional oil which would have to be marketed if the technology were not implemented. Basis for the calculation is explained in Appendix B of ERDA–48. These data are being reexamined, and changes will be made when analysis is completed. In a number of cases, revised projections of the impacts will be lower.

Technology	Term of Impact*	Direct Substitution for Oil & Gas**	RD&D Status	Impact in Year 2000 in Quads
GOAL I: Expand the Domestic Supply of Economically Recoverable Energy Producing Raw Materials				
Oil and Gas—Enhanced Recovery	Mid	Yes	Pilot	13.6
Oil Shale	Near	Yes	Study/Pilot	7.3
Geothermal	Mid	No	Lab/Pilot	3.1-5.6
GOAL II: Increase the Use of Essentially Inexhaustible Domestic Energy Resources				
Solar Electric	Long	No	Lab	2.1-4.2
Breeder Reactors	Long	No	Pilot/Demo	3.1
Fusion	Long	No	Lab	—
GOAL III: Efficiently Transform Fuel Resources Into More Desirable Forms				
Coal—Direct Utilization Utility/Industry	Near	Yes	Pilot/Demo	24.5
Waste Materials to Energy	Near	Yes	Comm	4.9
Gaseous & Liquid Fuels from Coal	Mid	Yes	Pilot/Demo	14.0
Fuels from Biomass	Long	Yes	Lab	1.4
GOAL IV: Increase the Efficiency and Reliability of the Processes Used in the Energy Conversion and Delivery Systems				
Nuclear Converter Reactors	Near	No	Demo/Comm	28.0
Electric Conversion Efficiency	Mid	No	Lab	2.6
Energy Storage	Mid	No	Lab	—
Electric Power Transmission and Distribution	Long	No	Lab	1.4
GOAL V: Transform Consumption Patterns to Improve Energy Utilization				
Solar Heat & Cooling	Mid	Yes	Pilot/Demo	5.9
Waste Heat Utilization	Mid	Yes	Study/Demo	4.9
Electric Transport	Long	Yes	Study/Lab	1.3
Hydrogen in Energy Systems	Long	Yes	Study	—
GOAL VI: Increase End-Use Efficiency				
Transportation Efficiency	Near	Yes	Study/Lab	9.0
Industrial Energy Efficiency	Near	Yes	Study/Comm	8.0
Conservation in Buildings and Consumer Products	Near	Yes	Study/Comm	7.1

* Near—now through 1985
Mid—1985 through 2000
Long—Post-2000
** Assumes no change in end-use device.

mates were used in ERDA–48 to project domestic petroleum and natural gas production.

The amount of oil and gas considered to be economically recoverable is subject to wide variations, reflecting different assumptions about undiscovered resources, technology, and price. Responsible estimates of remaining recoverable resources vary by a factor of two or more. All major estimates agree, however, that at current levels of use, domestic supplies of oil and gas cannot support projected energy demands for very long.

The implication of the USGS and NAS estimates is that current rates of oil and gas production by conventional methods will be difficult to maintain, even with additional Outer Continental Shelf and Alaskan production. Without enhanced recovery, the USGS estimates indicate that production of domestic oil and natural gas will begin to drop rapidly in the mid 1980's. It is unlikely that major new energy sources will be ready by that time.

New estimates of domestic recoverable resources may present a more optimistic picture. However, for purposes of planning for alternative RD&D programs, it is more prudent to use the lower band of existing estimates. In either case, as Dr. McKelvey, Director of the USGS, has said:

> . . . higher and lower estimates still carry the same message on several important policy questions. All indicate that substantial amounts of fluid hydrocarbons remain to be discovered if exploration is encouraged. All indicate that one of the largest

targets for future production is the oil presently remaining in place that might be available if recovery technology is advanced. All emphasize the importance of frontier areas, and all show that it is necessary soon to develop other sources of energy as the mainstay of our future energy supply.*

Specific Changes in Resource Estimates Since ERDA–48

Estimates of the major recoverable domestic resources are shown in Figure II-1. The shaded areas in this figure indicate the additional resources that may become recoverable if the technology can be developed to make this feasible. The figure and the estimates are identical to those presented in ERDA–48 with the following exceptions:

- **An increase in the estimate of coal resources.** The recoverable resource level, estimated at 12,000 quads in ERDA–48, has been increased to 13,300 quads (an 11 percent increase) to reflect a new resource assessment by USGS.** The new USGS estimate showed an overall 25 percent increase in total coal resources (including resources not currently considered economically recoverable).
- **The addition of solar energy to the recoverable resource base.** The estimate shown in the chart (43,000 quads per year) represents the average solar flux incident on the U.S. per year, and indicates the high contribution **potential** of this resource. However, significant technical problems are associated with the use of solar energy. Since energy flux is relatively low in energy value and is intermittent in a terrestrial application, the practical application of solar energy requires the availability of large collecting structures and energy storage. (For example, 20,000 to 30,000 acres of thermal collector area are required for a 1,000 megawatt electric plant at today's collection efficiences.) Furthermore, solar energy technologies and their applications will require varying degrees of further development before they can become economically viable. Some water and space heating systems are being introduced in the U.S.; however, considerable technological development is required before solar energy in other forms can be used efficiently and economically.
- **The addition of fusion to the recoverable resource base.** The estimate of 3 trillion quads reflects the

* Department of the Interior News release, May 1975.
** See Chapter VI for a more detailed assessment of this new assessment.

ENERGY AVAILABLE AND REQUIREMENTS IN QUADS (10^{15} BTU) SHOWN GRAPHICALLY BY AREA

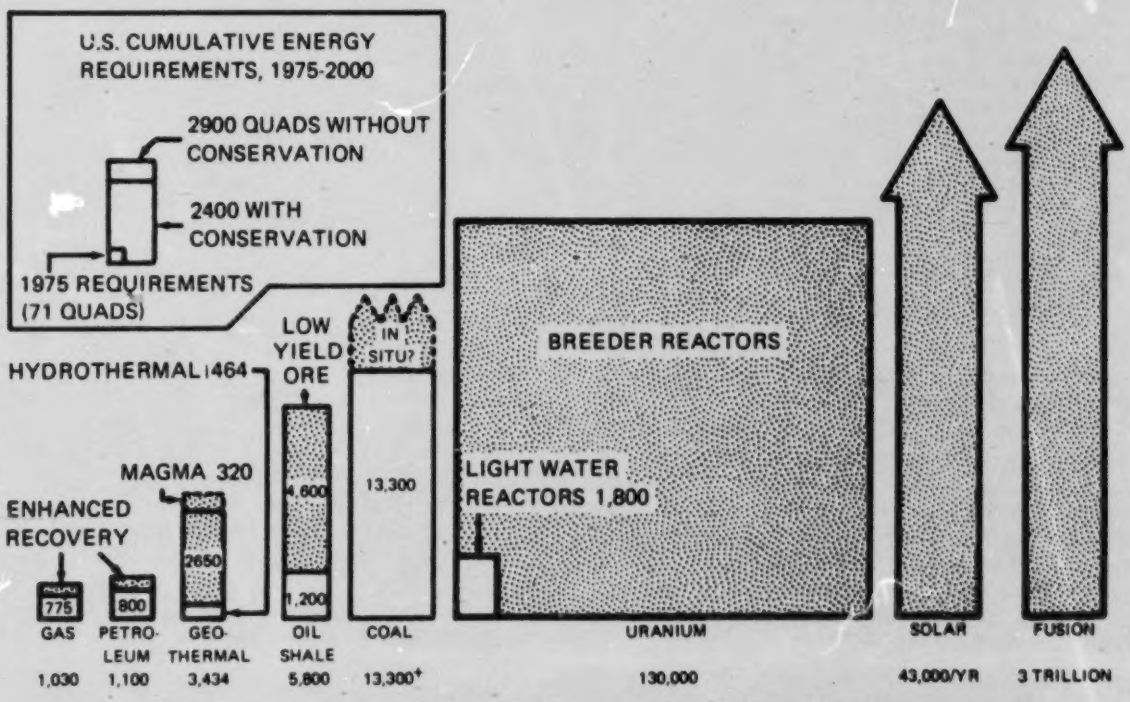


Figure II–1 Recoverable Domestic Energy Resources

potential energy that can be derived from the deuterium in the oceans. In theory, fusion energy is capable of providing all the energy needed for an indefinite period. Through the RD&D process, scientists are attempting to translate that theory into practice. Difficult scientific, engineering, and economic problems will have to be solved even after success has been achieved in producing the necessary controlled thermonuclear reaction. Nevertheless, the resource base is so large that success will ensure a virtually limitless energy source.

- **The addition of geothermal energy to the recoverable resource base.** The geothermal estimate is based on a new assessment of resources* that considers utilization of present or near-term technology without regard to cost. Most important currently is the recoverable heat portion of hydrothermal convective resources. In the mid term (1985–2000), the liquid-dominated hydrothermal resources and the geopressured resources (including dissolved methane) could become viable options, for both electric power generation or direct use as heat. The mid- to long-term (2000 and beyond) geothermal potential of the total heat resource within the earth's crust is undoubtedly very large, in the forms of hot dry rock, heat flows evidenced by temperature gradients that are either "normal" or enhanced by natural radioactive decay, and ultimately even magma (molten rock).
- **The addition of energy demand estimates (1975–2000) with and without conservation.** Energy conservation is shown to reduce the cumulative requirements by over 15 percent. The demand estimates are based on the scenarios contained in ERDA–48.

Implications of the Resource Estimates

Figure II-1 shows the relative paucity of domestic oil and gas resources compared to the estimated cumulative energy demand from now until the end of the century. Coal and nuclear represent the major exploitable resources to supplement oil and gas over the next several decades. Geothermal, oil shale, and solar energy (in the form of solar heating and cooling) represent supporting resources to ease overall supply problems during that time period. Nuclear breeders, solar electric, and fusion represent technologies that can exploit major resources for the next century; these technologies also have the potential to contribute to meeting energy needs during the latter part of this century.

In summary, even though the Nation is blessed with abundant energy resources, it is presently dependent upon a narrow base of diminishing resources. Accordingly, the National Plan for Energy RD&D describes likely options for introducing new technology that will assist the changeover from dependence on this narrow base of diminishing domestic resources to reliance on a broader range of less limited alternatives.

The transition to less limited resources poses substantial technological and environmental problems. Of equal importance are the difficult economic, social, and institutional problems that will be associated with this transition. An RD&D program, however successful technically, can fail because of failure to solve any one of these problems. These problems are addressed in later sections of this report.

Strategy and Priorities for RD&D

A National Plan for Energy RD&D should be guided by the policy and technology goals established. It must also reflect the reality of available domestic energy resources and the developmental status of technologies needed to use these resources. To translate the understanding developed thus far into an RD&D program, however, it is necessary to compare the potentials of the wide spectrum of technology options currently under investigation. Definitions of major technological options to be considered in the Plan are presented in the Glossary. Twenty-one major RD&D technologies and 14 supporting technologies are described.

ERDA–48 examined a number of combinations from the spectrum of technology options to establish both an overall strategy and specific energy RD&D priorities for the principal supply and demand technologies. Subsequent analysis, described in Chapter VI, has changed the strategy and priorities of ERDA–48 in one important respect:

Priority Ranking of Conservation now significantly increased. This major change from ERDA–48 reflects observation of only moderate progress to date on supply technologies, public comment on ERDA–48, and further analysis of conservation opportunities. Specific reasons for assigning higher priority to energy efficiency technologies are identified below. Many of the technologies to improve energy efficiency currently appear to have one or more of the following characteristics.

- A barrel of oil saved can result in reduced imports. Conservation combined with fuel substitution efforts reduces dependence on foreign oil. The focus is on cost-effective approaches since not everything that saves energy should be implemented at this time. Technology development should increase the number of cost-effective approaches available.
- It typically costs less to save a barrel of oil than to produce one through the development of new technology.

* See Chapter VI for a more detailed discussion of this new assessment.

- Energy conservation generally has a more beneficial effect on the environment than does energy produced and used.
- Capital requirements to increase energy-use efficiency are generally lower than capital needs to produce an equivalent amount of energy from new sources since most new supply technologies are highly capital-intensive.
- Conservation technologies can generally be implemented at a faster rate and with less government involvement in the near-term than can supply technologies.
- Energy efficiency actions can reduce the pressure for accelerated introduction of new supply technologies. Since the actions persist over time, the benefits are continuing in nature.

These reasons deal generally with conservative technologies. The rate of application and introduction of conservation technologies in specific instances will be determined by the comparative economics and social acceptability of the available alternatives.

Strategy of Energy Technology

With this revision, ERDA now views the likely order of technological change in energy supply and demand as follows:

For the near-term (now to 1985) and beyond, technology will help to:

- Increase the efficiency of energy used in all sectors of the economy and extract more usable energy from waste materials
- Preserve and expand major domestic energy systems: coal, light water reactors, and gas and oil from new sources and by enhanced recovery techniques.

For the mid-term (1985–2000) and beyond, technology will help to:

- Accelerate the development of new processes for producing synthetic fuels from coal and extracting oil from shale
- Increase the use of fuel forms such as geothermal energy, solar energy for heating and cooling, and extraction of more usable energy from waste heat.

For the long-term (past 2000), technology will help to:

- Permit the use of the essentially inexhaustible resources: nuclear breeders; fusion; and solar electric energy from a variety of options including wind power, thermal and photo-voltaic approaches, and ocean thermal gradients
- Provide the technologies to use the new sources of energy, which may be distributed as electricity, hydrogen, or other forms throughout all sectors of the economy.

Table II-2 presents the spectrum of technology options listed in Table II-1 in these strategic terms.

Table II–2 The Strategy of Technology Introduction

Time of Impact	Strategic Element	Technology	Impact in Year 2000 (Quads)
Near-term (now to 1985 and beyond)	Increase efficiency of energy use and convert waste to energy	Conservation in Buildings and Consumer Products	7.1
		Industrial Energy Efficiency	8.0
		Transportation Efficiency	9.0
		Waste Materials to Energy	4.9
	Preserve and expand oil, gas, coal, and nuclear	Coal-Direct Utilization in Utility/Industry	24.5
		Nuclear-Converter Reactors	28.0
		Oil & Gas Enhanced Recovery	13.6
Mid-Term (1985-2000 and beyond)	Accelerate development of synthetic fuels from coal and shale	Gaseous and liquid fuels from Coal	14.0
		Oil Shale	7.3
	Increase use of under-used (limited application) fuel forms and extract more usable energy from waste heat	Geothermal	3.1–5.6
		Solar Heating & Cooling	5.9
		Waste Heat Utilization	4.9
Long-Term (past 2000)	Develop the technologies necessary to use the essentially inexhaustible fuel resources	Breeder Reactors	3.1
		Fusion	—
		Solar Electric	2.1–4.2
	Develop the technology necessary to change the existing distribution systems to accommodate the distribution of new energy sources.	Electric Conversion Efficiency	2.6
		Electric Power Transmission & Distribution	1.4
		Electric Transport	1.3
		Energy Storage	—
		Hydrogen in Energy Supplies	—
		Fuels from Biomass	1.4

Table II-3 presents the strategy in more concrete terms—the numbers of energy facilities that would be built if all the technologies were successfully introduced. These estimates are not additive, since not all technologies must be introduced fully to satisfy demand in the year 2000.

While these tables are not prescriptive, they potentially provide a set of yardsticks useful in assessing the actual rate of technological introduction. Such assessments are essential to shaping the Federal role in developing energy* technology to fit progress being made in the private sector.

National RD&D Priorities

Based on an understanding of the strategic role of technology in solving the Nation's energy problem, it is possible to suggest what type of energy RD&D is most important. Several observations are helpful in understanding the nature and use of these priorities, presented in Table II-4.

1. **The highest supply and demand technology priorities stem directly from the strategic assessment described in the preceding section.**

Table II-3 Numbers of Major Facilities Potentially Required by Year 2000

Type of Energy Facilities	Number of Equivalent Facilities	
	Potentially Required in 2000	Existing in 1975
Fossil Power Plants (1000 MWe equivalent)	500–800	400
Nuclear Power Plants (1000 MWe equivalent)	450–800	37
Geothermal Power Plants (1000 MWe equivalent)	40–100	0.5
Solar Electric Power Plants (1000 MWe equivalent)	50–100	0
Coal Mines (one million tons/year equivalent)	1600–2370	640
Coal Liquefaction or Gasification Plants (50,000 b/d oil equivalent)	70–140	0
Oil from Shale Plants (50,000 b/d oil equivalent)	40–80	0
Buildings (millions) Solar Heated and Cooled	13–22	negligible
Heat Pumps (millions)	13–26	0.2
Electric Automobiles (millions)	10–20	negligible

Notes
- The list is non-additive because different technologies serve the equivalent energy markets in different scenarios.
- Source for the date is the ERDA-48 scenarios.
- MWe = megawatts electric
- b/d = barrels per day

2. **Under-used (limited application) mid-term technologies such as geothermal and solar heating and cooling are assigned only a moderate priority in the ranking.** However, certain applications of these technologies can have an impact on the Nation's energy demand in the mid term with the establishment of an industrial base. These technologies are important because they are sufficiently well-developed to be employed on a regional basis where the resources can be exploited economically. The geothermal resources and technologies included in this category are limited to hydrothermal and geopressurized applications, and the solar heating and cooling technologies may be limited to areas that enjoy high levels of insolation and experience relatively high costs for alternative fuels.

3. **A lower priority is assigned to technologies supporting intensive electrification, and to hydrogen and biomass systems.** Electrification technologies and hydrogen systems are likely to be very important to an economy powered by breeders, solar electricity, and fusion power. As the importance of electrification increases over time, the priorities for these technologies should also be increased. Further study may also reveal specific applications within the broad technologies that should receive a high priority now.

4. **Notwithstanding the differences in priorities, some work on all the energy technologies is appropriate now.** A number of factors support this conclusion:

- A specific RD&D can fail entirely, or can produce results much later than expected. It would thus be unwise to restrict the number of RD&D efforts on the assumption that anyone will be successful.
- The long lead times characteristic of the technologies for using inexhaustible resources require that RD&D be undertaken now to ensure their timely availability. Figure II-2 summarizes this problem.
- Only the successful development and implementation of a number of technologies in a combination of approaches can provide adequate solutions to the present energy problem.
- Curtailment of any major existing energy source (e.g., nuclear power) places heavy demands on all the remaining options.

These overall RD&D priorities have a number of uses, as well as some limitations. Both their uses and limitations are important to a proper understanding of the priorities.

- **The priorities help in assessing progress toward the energy technology goals.** RD&D is a precursor of technology introduction. Therefore, RD&D progress, or lack of it, provides early indications of whether the technological strategy is proceeding as planned.
- **The priorities form the basis for Federal action.** When any of the three Federal roles is justified, the priorities help determine its urgency.

Table II–4 Proposed National Ranking of RD&D Technologies*

HIGHEST PRIORITY DEMAND	
NEAR-TERM CONSERVATION (EFFICIENCY) TECHNOLOGIES	• CONSERVATION IN BUILDINGS & CONSUMER PRODUCTS • INDUSTRIAL ENERGY EFFICIENCY • TRANSPORTATION EFFICIENCY • WASTE MATERIALS TO ENERGY
HIGHEST PRIORITY SUPPLY	
NEAR-TERM MAJOR ENERGY SYSTEMS	• COAL-DIRECT UTILIZATION IN UTILITY/INDUSTRY • NUCLEAR-CONVERTER REACTORS • OIL AND GAS ENHANCED RECOVERY
NEW SOURCES OF LIQUIDS AND GASES FOR THE MID TERM	• GASEOUS AND LIQUID FUELS FROM COAL • OIL SHALE
"INEXHAUSTIBLE" SOURCES FOR THE LONG TERM	• BREEDER REACTORS • FUSION • SOLAR ELECTRIC
OTHER IMPORTANT TECHNOLOGIES	
UNDER-USED (LIMITED APPLICATION) MID-TERM TECHNOLOGIES	• GEOTHERMAL • SOLAR HEATING AND COOLING • WASTE UTILIZATION
TECHNOLOGIES SUPPORTING INTENSIVE ELECTRIFICATION	• ELECTRIC CONVERSION EFFICIENCY • ELECTRIC POWER TRANSMISSION AND DISTRIBUTION • ELECTRIC TRANSPORT • ENERGY STORAGE
TECHNOLOGIES BEING EXPLORED FOR THE LONG TERM	• FUELS FROM BIOMASS • HYDROGEN IN ENERGY SYSTEMS

*Individual Technologies are not ranked within the technology categories.

The priorities are not simply related to the allocation of ERDA RD&D resources. As outlined in Chapter I and discussed in detail in Chapters III and V, the chain of events from national priorities to ERDA programs is a long one. A Federal role must first be justified, and the relative importance of Federal RD&D—as opposed to other Federal actions—assessed. When Federal RD&D is indicated, ERDA may not be the appropriate agency to conduct the related programs. Further, the level of ERDA resource commitment is also influenced by the stage of technology development and the overall size of ERDA's budget.

Despite their limitations, these RD&D priorities should serve as a useful tool in linking both private and public RD&D to the national interests in energy technology.

Specific Supporting Technologies

Successful implementation of the RD&D strategy to develop and implement the primary RD&D technologies requires the concurrent development of technologies that provide specific support. The priority and status of these technologies, listed in Table II-5, derive from the technologies to which they relate.

The following list, originally included in ERDA-48, presents specific supporting technology activities:

- More rapid and complete assessment of domestic uranium resources

Table II–5 Supporting Technologies

Specific Supporting Technologies:	Exploration and Resource Assessment Mining and Beneficiation Environmental Control Technology Nuclear Safeguards Support to the Nuclear Fuel Cycle Uranium Enrichment Fossil Fuel Transportation Waste Management

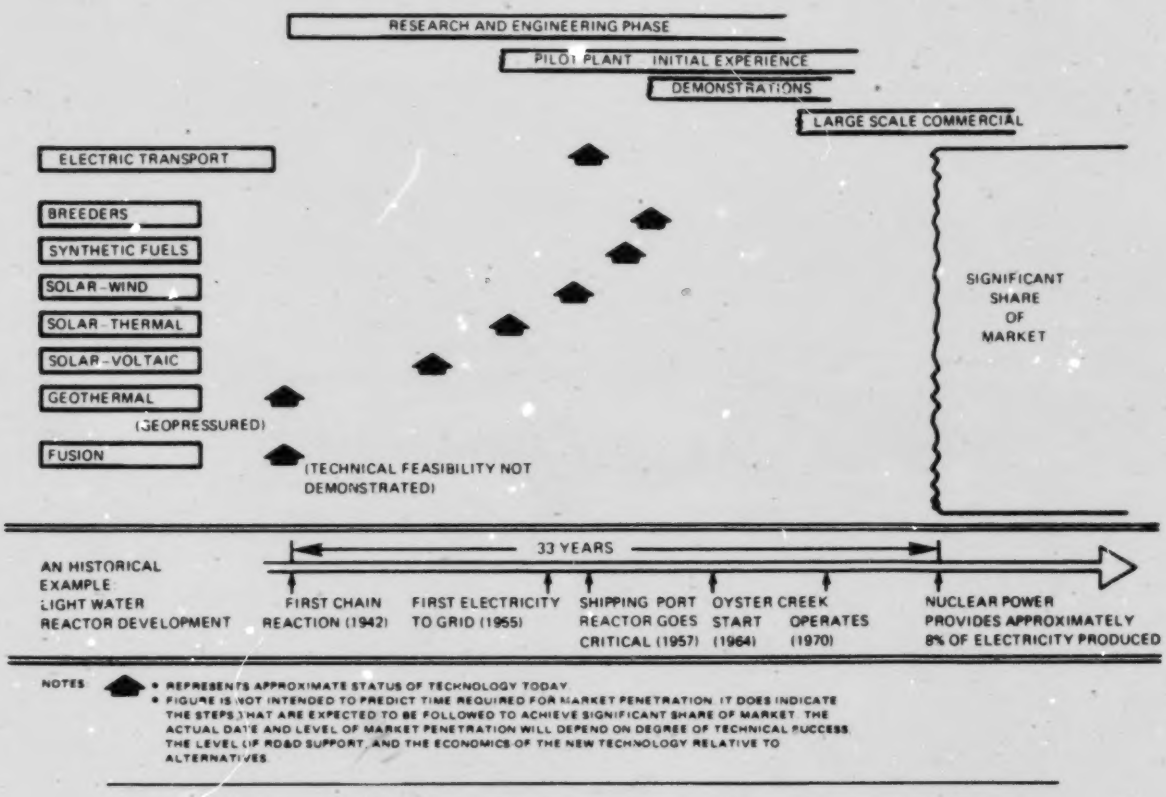

RESEARCH AND ENGINEERING PHASE
PILOT PLANT - INITIAL EXPERIENCE
DEMONSTRATIONS
LARGE SCALE COMMERCIAL
ELECTRIC TRANSPORT
BREEDERS
SYNTHETIC FUELS
SOLAR-WIND
SOLAR-THERMAL
SOLAR-VOLTAIC
GEOTHERMAL
(GEOPRESSURED)
FUSION
(TECHNICAL FEASIBILITY NOT DEMONSTRATED)
SIGNIFICANT SHARE OF MARKET
33 YEARS
AN HISTORICAL EXAMPLE LIGHT WATER REACTOR DEVELOPMENT
FIRST CHAIN REACTION (1942)
FIRST ELECTRICITY TO GRID (1955)
SHIPPING PORT REACTOR GOES CRITICAL (1957)
OYSTER CREEK START (1964)
OPERATES (1970)
NUCLEAR POWER PROVIDES APPROXIMATELY 8% OF ELECTRICITY PRODUCED
NOTES
• REPRESENTS APPROXIMATE STATUS OF TECHNOLOGY TODAY.
• FIGURE IS NOT INTENDED TO PREDICT TIME REQUIRED FOR MARKET PENETRATION. IT DOES INDICATE THE STEPS THAT ARE EXPECTED TO BE FOLLOWED TO ACHIEVE SIGNIFICANT SHARE OF MARKET. THE ACTUAL DATE AND LEVEL OF MARKET PENETRATION WILL DEPEND ON DEGREE OF TECHNICAL SUCCESS, THE LEVEL OF RD&D SUPPORT, AND THE ECONOMICS OF THE NEW TECHNOLOGY RELATIVE TO ALTERNATIVES.

Figure II–2 Status of Longer Range Technologies

- Expansion of coal availability and use through improved mining and environmental control technologies
- Increased effort toward understanding biomedical and environmental consequences of waste products generated and dispersed by fossil energy technologies
- Emphasis on resolution of nuclear safeguard issues to strengthen the viability of the nuclear option
- Increased effort on light water reactor fuel cycle technology where information and experience are required to resolve issues of chemical processing, plutonium recycling, and waste management
- Early expansion of the U.S. nuclear fuel enrichment capacity through diffusion, centrifuge, and other techniques.

Basic Energy Science and Environmental Research

Two of the energy technology goals do not involve direct supply and demand energy technology. They do, however, encompass two critical technological activities: basic energy science and environmental research.

Basic Energy Science

Basic energy science provides the seeds for future technological advances. The basic strategy of the National Plan for Energy RD&D is that the Nation must rapidly change to new energy technologies and new resource bases. Much of the research to accomplish this massive task will be developmental and applied, and will be performed by the private sector or in certain cases by the government.

To develop new knowledge relevant to the Nation's energy goals, an accompanying program of longer range, more fundamental research must also be established. Only by gaining new insights can major improvements be made in existing technologies, and entirely new concepts developed. Since the results of research cannot be predicted with any certainty, the apropriate level of support is based on subjective judgments of the possible future significance of technology needs and the nature of the uncertainties to be resolved rather than on objective analysis.

Fundamental research has to be supported largely by public funds. The private sector can and does perform excellent basic research in selected areas, but in general there is insufficient incentive for it to invest heavily in activities that can pay off

only in the long term. The return from research is unpredictable, and the results may not accrue to those making the initial investment.

A national program of basic energy science must include two types of research. One type addresses topics where the results, if successful, can be expected to form the foundation on which new or improved environmentally acceptable technologies can be built. For example, improved understanding of the strength and corrosion of structural materials, the fracture of rocks, or chemical reactivities and kinetics may have major impacts on many different development programs. Within ERDA, the focus is on those areas where the development of future energy technologies requires increased understanding.

The second type of research implicit in the overall national program is that directed toward the discovery of fundamental laws and principles. While past experience has indicated that the results of such research will probably be useful ultimately, this cannot be predicted except in the most general terms. The ERDA programs in medium and high energy physics are of this type. Both seek a deeper understanding of matter and energy at the most fundamental level. The research seeks to enhance man's culture and understanding of nature, which are values of great but intangible benefit.

Placing basic energy science in agencies responsible for meeting development and demonstration goals produces an element of conflict. Some feel that basic research thrives in an environment not dominated by demands for short-range applications; however, the ultimate usefulness of basic research is typically its primary justification. If rapid application of results is to occur, there must be a conscious effort to transfer fundamental results and insights to those responsible for development and demonstration.

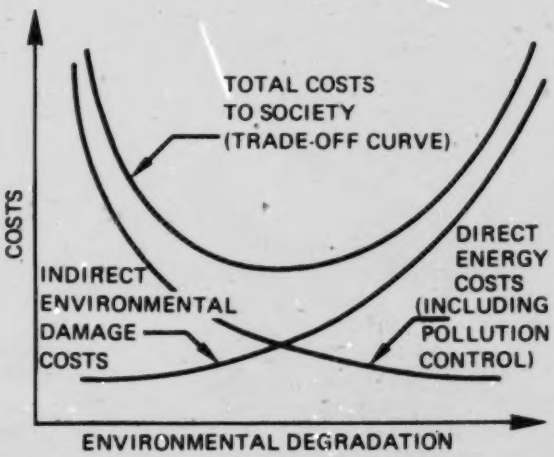
To effect this transfer of results, each federally supported technology program must have a component whose primary function is to bridge the basic-to-applied gap, serving as the point of contact between programs and the basic research activity. In this way, program requirements are translated into needed fundamental knowledge by the researcher, and new fundamental knowledge is translated into engineering concepts in the development and demonstration programs.

Environmental Research

Quality of life is measured not only in terms of the goods and services that an abundant and cheap energy supply can provide, but also in terms of human health and a clean environment. An energy future that promises inexpensive goods and services but that neglects the cost of damage to man and the environment is a poor bargain. Generally, however, the adverse impacts of technology can never be totally eliminated. Thus, the challenge is to create energy futures that are environmentally acceptable as well as technologically and economically viable.

"Environmental acceptability" implies a trade-off between the energy benefits sought, the consumer cost of energy, and the social cost of damages to human health and the environment. Environmental considerations are among the many factors that contribute to the need for alternative technology approaches; accordingly, they must be weighed carefully in the decision processes leading to the adoption, rejection, or modification of these alternatives. This integration of environmental considerations into the ERDA decision-making process is discussed further in Chapter V of this report. However, it must be recognized that major environmental issues will be resolved not through technology alone, but also through social processes. Hence, public dissemination of the implications of technology alternatives is mandatory to permit socially optimal choices.

In general, at a given level of energy production, the direct cost of supplying energy to the consumer decreases as such associated processes as land reclamation, waste disposal, and air and water pollution control are minimized or neglected. Thus, the direct cost of energy decreases as environmental restrictions are eased. At the same time, indirect social and environmental costs (e.g., pollutant-induced diseases, disabilities, shortened lifespans, deterioration of buildings, reduced productivity) increase as environmental degradation increases. These trends are shown in Figure II-3.



NOTE: DIRECT ENERGY COSTS + INDIRECT ENVIRONMENTAL DAMAGE COSTS = TOTAL COSTS TO SOCIETY.

Figure II–3 Conceptual Environment/Cost Trade-Off Curve at a Fixed Level of Energy Production

The sum of the direct energy costs and the indirect social and environmental costs represents the total cost to society. In theory, this curve should exhibit a minimum cost value. Society may choose to pay more than this minimum cost in one of two ways. The first, to the right of the trade-off curve, is the historical approach in which the direct energy costs to a particular consumer are minimized, and the increased indirect environmental and social costs are either spread over the whole society, or worse, paid for by a different element of the public. The other approach, to the left of the curve, is when society decides to reduce environmental degradation still further. It seems reasonable that society's choice would be to the left of the minimum cost as long as society believes that the marginal benefit exceeds or equals the marginal cost.

While the curves shown in Figure II-3 are illustrative only, they represent the technology/environment trade-off relationship. The responsibility of energy RD&D is to change the shape of the trade-off curve over time to afford the public greater environmental protection for the same cost or equal protection at less cost. A number of Federal agencies, including ERDA, have been assigned responsibility to pursue RD&D to accomplish this result.

Addressing the energy/environment trade-off from the social rather than RD&D viewpoint, a relationship can also be established among the level of energy production, direct energy costs, and indirect environmental costs. In brief, if either the direct energy costs or indirect environmental costs become too great, society can either invest in new technologies and/or resource bases with lower penalties or settle for a lower level of energy production.

This analysis highlights a real responsibility to identify available energy alternatives and to improve knowledge of their environmental implications. Extensive research must be conducted if the public is to be informed of the true nature of trade-offs and the implications of the various choices. This approach is expected to be one way in which environmental perspectives can be introduced into the ERDA decision-making process. Insights derived therefrom can affect ERDA's view of priorities in both technology development and environmental research.

Strategic Elements of Environmental Policy

The overriding challenge to energy RD&D is thus to establish a spectrum of technology options capable of significantly reducing the social costs of energy production while providing economically attractive benefits for energy suppliers and consumers. To meet this challenge, the environmental RD&D strategy developed must contain the following elements:

- Early identification and characterization of the environmental issues and public concerns associated with the commercial operation of energy systems
- Establishment of standards of environmental performance for each technology concept to spur innovations aimed at reducing the severity of environmental impacts and the cost of their control
- Continuous interaction with the public, private organizations, and other governmental agencies to ensure current awareness of public concerns regarding energy developments and environmental RD&D, as well as wide dissemination of information on environmental problems and progress.

Within ERDA, the following operational philosophy guides environmental RD&D:

- Environmental performance is considered an integral part of energy technology performance and is assigned competitive priority within each technology program. Environmental activities thereby command sufficient resources to achieve major program milestones.
- Protection of the health and safety of workers and the general public from potentially adverse impacts of energy is a basic performance standard for all energy technologies.
- In conformance with the spirit of the National Environmental Policy Act,* detailed environmental planning focused on key decision points constitutes an essential part of every program plan. An agency-wide environmental and safety overview function assesses changes in resource priorities, scheduling, and environmental performance goals.
- Public involvement programs and environmental RD&D coordination activities at both the agency and the technical program level are conducted to ensure that: (1) technical and policy decision-makers are fully informed about related external activities, perceptions, and problems, (2) environmental activities are coordinated effectively, and (3) all outside groups gain a realistic view of ERDA's and the Nation's environmental progress and problems related to energy.

It will take some time before the environmental RD&D strategy is fully implemented either nationally or within ERDA for all near-, mid-, and long-term technologies. First priority must be assigned to achieving market penetration of near-term technologies, as discussed in Chapter III. In recognition that decisions concerning the benefits and risks of the immediate energy future must be made soon, environmental activities in ERDA and throughout the Federal RD&D establishment reflect this near-term emphasis. Chapter III includes a discussion of the

* Public Law 91-190.

major health and environmental problems affecting market penetration of near-term technologies and the approaches the Federal RD&D establishment is pursuing to resolve those problems.

Since knowledge of the identity, character, and methods for mitigating near-term environmental risks is far from complete, RD&D planning must place heavy emphasis on the rapid acquisition of environmental information and innovation in the near-term. The planning process, however, cannot neglect mid- and long-term environmental problems. Environmental planning and implementation must therefore ensure support for long-term environmental RD&D in the face of pressures to turn full attention to near-term demands.

To ensure that appropriate environmental RD&D priorities are maintained and that ERDA resources are allocated to produce environmentally acceptable energy technology options over the long-term, a formal environmental planning process is being structured within ERDA. Chapter V includes a description of this ERDA environmental planning process.

Chapter III—The Plan and The Federal Energy RD&D Program For FY 1977

Laying out the fundamentals of the Plan, as was done in the preceding chapter, in terms of the objectives and goals to be attained and the programmatic priorities for action is the first step in building the National Plan for Energy RD&D. To be complete, however, a plan needs to indicate how the objectives it has set are to be achieved—i.e., how resources are to be deployed, how problem areas are to be addressed, and how responsibilities are to be assigned.

As indicated earlier, the private sector must play the predominant role in market penetration of new energy technologies. The energy situation is thus completely unlike the Manhattan Project or the Apollo Program in that in those cases, virtually all activities were undertaken or directed by the Federal Government.

This chapter, therefore, focuses on the narrower set of activities that the Federal Government can appropriately undertake, within our Nation's free enterprise system, to carry forward its portion of the total national effort. Accordingly, this chapter covers: (1) the budgetary decisions made by the Federal Government to support specific energy technologies; and (2) the overall programmatic approaches to be adopted for each of those technologies. The two subsequent chapters deal with the institutional mechanisms and decision-making processes that appear central to carrying out the Plan.

The FY 1977 Budget

The ERDA National Energy RD&D Plan served as an important input to the development of the President's amended 1976 and 1977 budget requests for energy RD&D funding.

Table III–1 President's National Energy Program FY 1977 Budget

(Outlays in millions of dollars)

	FY 1976		FY 1977†		Percent Change
	$	%	$	%	
Program Activities					
Domestic energy resource development, conservation and petroleum storage (e.g., FEA, Energy Independence Authority, TVA & power administration, uranium enrichment)*	5,516	69%	7,259	70%	+32%
Energy research, development and demonstration (e.g., ERDA, Interior, NRC, et al.)	2,231	28%	2,905	28%	+30%
Regulation (REA, FPC, MESA, NRC)*	234	3%	244	2%	+ 4%
Total outlays	7,981	100%	10,408	100%	+30%
Less: Receipts (TVA, NPR, uranium enrichment)*	−3,385		−4,355		+29%
Net outlays	4,596		6,053		+32%

† Funds for FY 76 Transition Quarter are not included.
* Based on: "Seventy Issues—Fiscal Year 1977 Budget," OMB

Table III-1A Federal Energy R&D (Dollars in millions)

	FY 75		FY 76*		FY 77	
	BA	BO	BA	BO	BA	BO
Direct Energy R&D						
ERDA	$1,317.0	$1,011.0	$1,657.0	$1,427.0	$2,435.0	$2,009.0
DOI	89.9	54.2	104.0	93.3	98.3	96.3
EPA	80.8	18.2	56.8	76.6	55.4	76.6
NRC	58.9	51.7	87.5	76.9	104.0	98.2
NASA	0.8	0.8	1.7	1.0	–0–	0.8
Subtotal	1,547.4	1,135.9	1,907.0	1,674.8	2,692.7	2,280.9
Supporting R&D						
ERDA	362.0	313.0	403.0	373.0	430.0	404.0
DOI	33.2	30.9	59.0	56.7	66.8	65.2
EPA	53.2	5.0	43.2	43.4	41.6	43.4
NRC	2.3	2.1	9.6	9.1	5.3	5.0
NSF	103.2	65.9	114.6	74.2	123.4	106.9
Subtotal	553.9	416.9	629.4	556.4	667.1	624.5
Total Federal Energy R&D	$2,101.3	$1,552.8	$2,536.4	$2,231.2	$3,359.8	$2,905.4

* Funds for FY 76 Transition Quarter are not included.

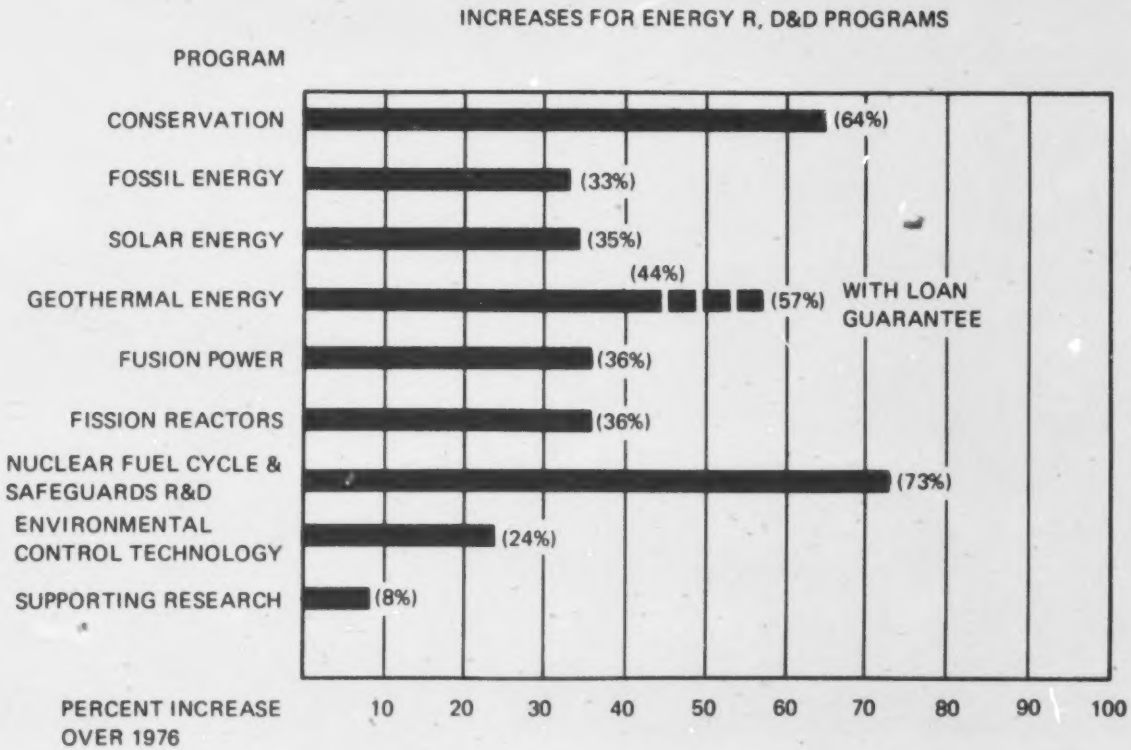


Figure III–1 Energy Research and Development Administration FY 1977 Budget

Table III-2 Federal Energy R&D Budget Exclusive of ERDA (Authority in millions)

	FY 75	FY 76*	FY 77
Energy RD&D Programs			
Nuclear Fuel Cycle and Safeguards	6.6	14.4	25.0
Conservation	4.1	5.7	1.2
Geothermal	10.9	12.2	5.9
Fusion	–0–	–0–	–0–
Fission	57.6	78.7	85.0
Solar	0.8	1.7	–0–
Fossil	69.6	80.0	84.7
Environmental Control Tech.	80.8	57.3	55.9
Subtotal	230.4	250.0	257.7
Supporting Research			
Basic Energy Sciences	84.6	95.8	103.6
Environmental Research	107.3	130.6	133.5
Subtotal	191.9	226.4	237.1
Total Non-ERDA Energy RD&D	422.3	476.4	494.8

* 76 dollars do not include transition quarter.

Table III-3 Federal Energy R&D Budget Exclusive of ERDA (Outlays in millions)

	FY 75	FY 76†	FY 77
Direct Energy R&D			
Nuclear Fuel Cycle and Safeguards	6.3	13.7	23.9
Conservation	1.3	7.0	1.9
Geothermal	10.7	10.1	5.8
Fusion	–0–	–0–	–0–
Fission	50.6	68.7	80.2
Solar	0.8	1.0	0.8
Fossil	37.0	70.2	82.2
Environmental Control Tech.	18.2	77.1	77.1
Subtotal	124.9	247.8	271.9
Supporting Research			
Basic Energy Sciences	55.5	62.8	89.7
Environmental Research	48.4	120.6	130.8
Subtotal	103.9	183.4	220.5
Total Non-ERDA Energy RD&D	228.8	431.2	492.4

† Funds for FY 76 Transitional Quarter are not included.

Table III-4 ERDA Energy Related Budget FY 75–76–77 (Authority in millions)

	FY 75	FY 76†	FY 77	FY 76 to FY 77 percent change*
Energy RD&D Programs				
Nuclear Fuel Cycle and Safeguards	$ 118	$ 173	$ 347	101
Conservation	36	75	120	60
Geothermal	28	31	100**	223
Fusion	183	250	392	57
Fission	567	602	823	37
Solar	42	115	160	39
Fossil	335	398	477	20
Environmental Control Tech.	8	13	16	23
Subtotal	$1,317	$1,657	$2,435	
Supporting Research				
Basic Energy Sciences	191	210	227	8
Environmental Research	171	193	203	5
Subtotal	362	403	430	
Total ERDA Energy RD&D	$1,679	$2,060	$2,865	

† 76 dollars do not include transition quarter.
* Percentage change calculated prior to rounding authority.
** Includes $50 Million for Geothermal Loan Guarantee Program.

Table III-5 ERDA Energy R&D Budget (Outlays in millions)

	FY 75	FY 76†	FY 77	FY 76 to FY 1977 percent change*
Direct Energy R&D				
Nuclear Fuel Cycle and Safeguards	$ 120	$ 163	$ 282	73
Conservation	21	55	91	64
Geothermal	21	32	50	57
Fusion	151	224	304	36
Fission	538	522	709	36
Solar	15	86	116	35
Fossil	138	333	442	33
Environmental Control Tech.	7	12	15	24
Subtotal	$1,011	$1,427	$2,009	
Supporting Research				
Basic Energy Sciences	$ 165	$ 188	$ 205	9
Environmental Research	148	185	199	7
Subtotal	$ 313	$ 373	$ 404	
Total ERDA Energy RD&D	$1,324	$1,800	$2,413	

† Funds for FY 76 Transition Quarter are not included.
* Percentage change calculated prior to rounding outlays.

In FY 1977, as compared with FY 1976, Federal outlays for all energy activities combined have increased about 30 percent to a net level of $6 billion. Similarly, the energy RD&D portion of this total has also increased over 30 percent, to a level of over $2.9 billion. Table III-1 and III-1A summarize this information as adapted from the January 21, 1976 document, **Seventy Issues—Fiscal Year 1977 Budget,** prepared by the Office of Management and Budget. Tables III-2 and III-3 are a breakdown of the energy RD&D portion of the Federal energy budget by agency. Table III-4 and III-5 and Figure III-1 are a breakdown of the ERDA energy RD&D budget by technology area, showing percentage changes for FY 1977 of selected major programs.

Although the year-to-year percentage changes reflect program priority, they also reflect program **status.** Thus a new program, such as Conservation, may receive a lower absolute level of funding, but a level significantly higher than the preceding year or years. On the other hand, older programs may require very expensive technology and large demonstration plants, which entail large absolute expenditures but not necessarily a level of expenditure significantly higher than the preceding year. Budget decisions are designed also to encourage cost-sharing with private industry (e.g., coal liquefaction demonstration) and to avoid undertaking shorter term RD&D that is more appropriately the responsibility of the private sector (e.g., in areas of conservation technology). The extent to which the current budget has been successful in sharing the cost of programs with non-Federal organizations is shown in quantitative form in Table III-6. Specifically, of the total expected costs over $5 billion for ERDA cost-shared programs, non-Federal organizations are prepared to bear about 30 percent of the funding burden. This funding will facilitate a broad range of activities, including demonstration of a fission power breeder reactor, electric energy systems, solar heating and cooling of buildings, conservation techniques in operating commercial restaurants, and coal liquefaction.

Table III–6—ERDA Cost-Shared Program Areas with Non-Federal Organizations
(in $ millions)

	ERDA Estimated Investment	Non-Federal Organizations Investment	Total Estimated Cost (TEC)	Non-Federal Cost as Percent of TEC
Fossil*	1967	1257	3224	39
Geothermal**	7	5	12	42
Conservation	94	116	210	55
Fusion (Only Laser)	15	33	48	69
Fission***	1967	283	1981	14
Total	3780	1694	5475	31

* Does not include demonstration plants
** Funding of most plants yet to be determined
*** Primarily Clinch River Breeder Reactor

The major thrusts of ERDA's Energy RD&D budget for FY 1977, discussed in the order of program priority ranking laid out in Chapter II, can be summarized as follows:

—**Conservation** received a substantial funding increase from FY 1976 amounting to 64 percent. Conservation together with gradual deregulation of oil prices was an important element of the Energy Policy and Conservation Act. This funding supports a greatly expanded program to improve technology and encourage conservation of energy in buildings, industry and transportation.

—**Light Water Reactor Fuel Cycle** funding was increased by 73 percent from the previous year to assist the private sector in "closing the fuel cycle"—i.e., reprocessing and refabrication of nuclear fuel; developing acceptable technical and environmental approaches for the long-term storage of commercial reactor wastes; and insuring safeguards of nuclear materials.

—**Coal Direct Utilization** program funding was increased from past levels to support the continuing program and to permit construction of additional demonstration plants.

—**Enhanced Oil and Gas Recovery** program funding provides for continuation of ongoing programs and additional field demonstrations in partnership with industry.

—**Synthetic Fuels** program funding will be requested in a supplemental FY 1976 budget request to provide financial incentives to develop a synthetic fuels industry.

—**Essentially Inexhaustible Energy Technologies,** i.e., breeder reactor, fusion, and solar electric—all had their funding increased upwards of 30 percent reflecting the critical long-term need for these programs.

As can be seen, the ERDA FY 1977 Energy RD&D budget reflects the major objectives set forth in the President's 1976 Energy Message; the national priorities in the National Plan for Energy RD&D; the application of criteria for determining the appropriate Federal role as set forth in Chapter II; and the principles set forth directly above to arrive at appropriate budget levels for the Federal Program.

The overall Federal budget strategy is best captured by quoting selected portions relating to energy RD&D directly from the OMB document **Seventy Issues:**

"The Nation has undeveloped reserves of coal, oil, gas and uranium. There are also many opportunities to conserve energy. A solution to the dependence problem can be achieved with a longer term effort directed toward increasing domestic energy supplies and achieving greater conservation. The

President's national energy program is a comprehensive approach designed to achieve a capability for energy independence by 1985. The program includes both short-term and longer term initiatives but places basic reliance on the private sector to carry out expanded domestic energy supply production and conservation, and by developing a strategic storage petroleum system that will be capable of easing the impact of any embargo.

"The 1977 budget outlay estimates reflect the President's strong emphasis on domestic energy production, conservation and petroleum storage programs and massive R&D efforts to develop new energy technologies.

Domestic Energy Resource Development, Conservation and Storage

"Development and conservation of energy resources are essential to achieving greater independence from foreign petroleum supplies. These programs encourage the development of oil, gas, coal and uranium reserves, energy production, strategic petroleum storage, and more energy efficient process. Highlights contained in the FY 1977 budget include:

- **"Energy Resource Development, Production, Conservation**
  - —**"Energy Independence Authority**—Proposed establishment of an Energy Independence Authority with $100 billion in equity and funding authority to provide assistance (mainly loans and loan guarantees) to the private sector to encourage the development of energy projects using conventional technology (e.g., fossil and nuclear power plants) and emerging technologies (coal to gas plants, oil shale to oil). The Authority will also work to shorten the time required for energy projects to obtain clearances and permits from Federal regulatory agencies.

  * * * * *

  - —**"Uranium Enrichment**—Uranium enrichment is one of the processes required to convert uranium ore into usable fuel for nuclear power plants. At the present time, this activity is carried out in three Government-owned production facilities originally built for defense purposes.
  - —"In order to relieve the taxpayer of the financial burden of funding the construction of additional uranium enrichment facilities and to assure the availability of fuel for nuclear power plants, the President has proposed legislation required to foster the creation of a private competitive uranium enrichment industry in the U.S.
  - —"To produce a large enough stockpile to meet potential future needs, the FY 1977 budget will provide a substantial increase for (a) the production of enriched uranium and (b) the continuation of the previously approved expansion of the capacity of the current ERDA plants. However, the Administration believes that future expansion of enrichment capacity should be financed by the private sector with necessary Government cooperation and temporary assurance under the proposed Nuclear Fuel Assurance Act.

  * * * * *

  - —**"Energy Conservation**—Conservation proposals to: provide $55 million in financial assistance to low-income homeowners for insulation, establish thermal efficiency standards for new residential and commercial buildings, encourage appliance manufacturers to improve energy efficiency and to label appliances, and encourage auto manufacturers to increase fuel economy. The Energy Policy & Conservation Act makes the appliance labeling and auto fuel economy standards mandatory.
  - —**"Energy/Environment** — Amendments to the Clean Air Act to provide a needed balance between environmental and energy goals.
  - —**"Energy Tax Expenditures**—Tax expenditures to encourage the development and production of energy and mineral resources. Exploration and development expenses (mostly for oil and gas) may be treated as current costs rather than as capital investments, which are depreciated over a number of years. This provision is expected to provide a $1 billion incentive to develop energy resources in 1977. Another tax provision allows the use of percentage depletion rather than actual cost depletion. Although sharply curtailed for oil and gas in 1975 legislation, it is still expected to offer a $1.6 billion tax incentive for mineral production in 1977, with most of that amount for fossil fuel production. The Administration has proposed a package of tax aids for electric utilities that will especially help generating facilities not using oil or gas as fuels. It is estimated to provide $0.8 billion of tax relief in 1977.

  * * * * *

Energy Research, Development and Demonstration

"The Energy Research and Development Administration, proposed by the Administration, was established in January 1975 to be the major Federal agency for the conduct of energy research and development. In FY 1977 ERDA will provide 83% of the total Federal funding [outlays] for energy R&D. It also provides a central Federal agency for the planning and coordination of Federally sponsored energy research and development.

* * * * *

- **"Overall Energy R&D Budget Strategy**
  - —"Accelerate energy research and development

programs directed at achieving greater long-term energy independence.

—"Expand efforts to assure the safety, reliability, and availability of commercial nuclear power plants by increasing R&D on the long-term storage of radioactive wastes, fuel reprocessing, and safeguards against theft of nuclear materials.

—"Place greatest funding on technologies with the highest potential payoff in terms of recoverable resources (i.e., nuclear and fossil).

—"Continue to expand the investigation of other technologies where they can make significant contributions to meeting the long-term energy requirements of the U.S. (i.e., solar, geothermal, and conservation R&D).

—"Encourage cost-sharing with private industry (e.g., coal liquefaction demonstrations) and avoid undertaking shorter term R&D more appropriately the responsibility of the private sector (e.g., in areas of conservation technology).

—"Support the commercial demonstration of synthetic fuel production from coal, oil shale, and other domestic resources by providing loan guarantees during FY 1976 (upon enactment of the Energy Independence Authority legislation in FY 1977, transfer these projects to EIA).

- **"Non-nuclear Energy R&D**

—**Balance between nuclear and non-nuclear energy R&D**—The table of direct ERDA spending indicates more effort on nuclear than non-nuclear energy R&D. However, direct ERDA spending is not a true measure of the total national effort on non-nuclear energy R&D and greatly understates the effort being made to develop and commercialize non-nuclear energy technologies.

—"Although specific data is not available, private industry is known to be spending much more on non-nuclear energy R&D than on nuclear energy R&D (which has higher technical and regulatory uncertainties).

—"The Administration plans to support legislation which is expected to provide about $6 billion of loan guarantees in FY 1976–1978 to enable industry to construct facilities for producing synthetic fuels.

—"About $50 million per year will also be provided for loan guarantees for geothermal production projects.

—**"Fossil energy development**—Accelerate the development and demonstration of technology to (a) enable plentiful domestic coal resources to be substituted for increasingly scarce supplies of oil and natural gas; (b) increase the efficiency of the use of fossil fuels through advanced power conversion systems; and (c) increase the recovery of oil and natural gas from fields in the U.S.

—**"Solar energy development**—Increase the development and demonstration of solar energy applications, including 226 [awards involving 325 to 480] units to demonstrate solar heating and cooling in residential and commercial buildings and acceleration of technology for the conversion of solar energy to electricity.

—**"Geothermal energy development** — Expand R&D required for the utilization of U.S. geothermal resources including improving the capability for defining the extent and availability of such resources, developing advanced engineering techniques and building pilot plants. Provide $50 million in FY 1977 for loan guarantees to enable industry to proceed with geothermal production projects which would otherwise not be undertaken because of current technical and economic uncertainties.

—**"Conservation R&D**—Provide an expanded program to improve technology and encourage conservation of energy in buildings, industry, and transportation.

- **"Nuclear Energy R&D**

—**"Fusion**—Continue research to determine the scientific feasibility of obtaining virtually unlimited power for the long-term (beyond the year 2000) from the controlled thermonuclear fusion reaction. In FY 1977 continue construction on the $215 million Tokamak Fusion Test Reactor at Princeton, N.J., which will represent a major milestone.

—**"Fuel Cycle and Safeguards**—Improve the use of current commercial nuclear reactors.

—**"Commercial waste management**—Greatly accelerate the conduct of R&D to provide the technology for the terminal storage of radioactive wastes from commercial power plants by demonstrating this technology at several sites.

—**"Nuclear fuel reprocessing**—Assist industry by conducting R&D on the technology for reprocessing and reusing spent nuclear fuel discharged from commercial nuclear power plants.

—**"Safeguards** — Demonstrate techniques for safeguarding nuclear materials against theft.

—**"Uranium enrichment R&D** — Develop and demonstrate improved techniques for uranium enrichment which offer the promise of more efficient production and cheaper electricity for consumers.

- **"Other Direct Energy R&D**

—"Significantly increase outlays for the Nuclear Regulatory Commission's safety research pro-

gram and the Department of Interior's mining R&D program.

—"Reduce outlays for the Environmental Protection Administration's development of environmental control technology because of the completion of portions of major contracts and the increasing responsibility of other agencies in this area.

- **"Supporting Energy R&D**
  —"Continue the FY 1976 level of effort on programs to (a) determine the biomedical and environmental effects of nuclear and nonnuclear energy sources to assure development of safe energy technologies and (b) solve fundamental scientific and engineering problems that constrain the development of energy technologies.
- **"Synthetic Fuels**
  —"Support legislation to provide $2 billion in loan guarantees for industry ($500 million of Budget Authority) during 1976 for the commercial demonstration of synthetic fuel production from coal, oil shale, and other domestic resources. A total of $6 billion in loan guarantees is expected to be necessary over the 1976–1978 period in order to reach the 1985 objectives of 350,000 barrels per day of synthetic fuel production capacity. . . .

* * * * *

- **"Nuclear Regulation**—Funding for the Nuclear Regulatory Commission will increase 15% because of the important role NRC plays in ensuring that nuclear power continues to be a safe and environmentally acceptable means of generating electricity. The United States needs additional nuclear power plants in order to achieve more energy independence from foreign suppliers and to provide consumers with cheaper electricity than alternative sources can provide. The additional resources for NRC will help enable the U.S. to achieve the benefits of nuclear power by assuring adequate attention to the problems of safety, environmental effects, and safeguarding nuclear materials against theft.
- **"Nuclear Licensing**—A legislative proposal to streamline the NRC procedures for licensing nuclear power plants to reduce the amount of time required to process applications while maintaining safety and environmental standards.

Need for Initiative to Develop Domestic Energy Resources

"It is essential that the Nation move promptly to develop domestic energy resources to assure that needed supplies are available in the long run to avoid a growing dependence on foreign energy supplies. The Nation's energy situation continues to deteriorate.

* * * * *

Presidential Proposal for Energy Independence Authority

"To encourage needed domestic energy development and conservation, the President has proposed the establishment of a government corporation, the Energy Independence Authority (EIA) with $100 billion in financial resources to help achieve greater energy independence.

* * * * *

"Specific types of projects which EIA could provide financial and regulatory assistance would be limited to commercialization of:

—"Emerging energy technologies, such as synthetic fuels, not yet in widespread domestic commercial operation.

—"Technologies essential to production of nuclear power.

—"Conventional or emerging technologies for production and transmission of electric power generated by sources other than oil and gas.

—"Conventional energy technologies for the production or transportation of energy that are of such size or scope that they would not otherwise be financed by the private sector.

* * * * *

1977 Budget
ERDA Synthetic Fuels Commercial Demonstration Program
($ millions)

	1976* Budget Authority	1976* Outlays	1977 Budget Authority	1977 Outlays
Loan Guarantee Fund	500	—	—	—
Administrative Expenses	3	3	—	—
Total	503	3	—	—

* The loan guarantee fund will cover $2 billion in guarantees to initiate the program in 1976. The guarantee program will be transferred to the Energy Independence Authority in 1977 upon its enactment.

Need for the Program

- "U.S. dependence on foreign sources of oil and gas continues to grow with domestic production having fallen in the last several years.
- "Even using advanced oil and gas recovery techniques, extensive production from the Outer Continental Shelf and Alaska, improved energy conservation, expansion of nuclear power facilities, and greater direct burning of coal, oil imports will continue to rise substantially if synthetic fuel production capacity is not available by the middle 1990's. Synthetic gas and liquid fuels can be obtained from the processing of coal, oil shale, biological waste, and other domestic resources not now being fully utilized.
- "Initiating a synthetic fuels industry capable of

providing about 5 million barrels/day of production capacity (i.e., about 100 major plants) by 1995 will require early resolution of a number of uncertainties related to regulation, environment, financing, labor and transportation. The lead time to initiate such an industry requires the construction and operation, over the next 5 to 10 years, of a variety of synthetic fuel plants to obtain the needed data and information.

The President's Proposal

- "In his 1975 State-of-the-Union message, the President proposed the first important step toward the development of a synthetic fuels industry—a federally sponsored Synthetic Fuel Commercial Demonstration Program. An extensive interagency study concluded that the synthetic fuels program should proceed in two phases, the first of which would involve the construction and operation of about 12–15 commercial-size plants and would result in total synthetic oil and gas production equivalent to 350,000 barrels per day of oil. The second phase might begin in 1978 or 1979 and raise production to 1 million barrels per day, but this depends on the results of R&D efforts, additional information on environmental impacts, and the private sector's response to the first phase.
- "Although a $6 billion program of loan guarantees to implement aspects of the President's proposal was passed by the Senate during the last session, it failed to pass the House of Representatives.

Support for the Program in the 1977 Budget

- "The President is again supporting immediate creation, in 1976, of a synthetic fuels commercial demonstration program in the Energy Research and Development Administration. This program will be carried forward in ERDA until such time as the Energy Independence Authority is enacted and the program can be incorporated under that Authority.

—"As a first step in implementing this program, the 1977 budget provides for FY 1976 supplemental funding of $503 million in budget authority to cover $2 billion in loan guarantees for the remainder of 1976.

—"Additional budget authority to cover the full $6 billion loan guarantee program for Synthetic Fuels, which the Administration supported in 1975, is included in the 1977 Budget under the Energy Independence Authority.

Need for the Program

—"The U.S. needs more nuclear power.

- "Although domestic coal supplies are extensive and accessible, their use is severely limited by environmental constraints. Widespread use of coal without relaxing environmental standards will require new clean conversion technologies (e.g., gasification or liquefaction of coal) or those permitting direct use of coal (e.g., sulphur removal from exhaust gases).
- "Recovery of potentially significant solar and geothermal resources is currently limited by technological and economic uncertainties. Their economical use will require development of new or improved technologies.
- "The U.S.'s most plentiful domestic resources are coal and nuclear. Neither one alone could be sufficiently developed to meet all our energy needs over the next few decades due to limitations on required transportation and other supporting facilities and equipment manufacturing capacity. Both coal and nuclear must be exploited to achieve energy independence from foreign suppliers.
- "Furthermore, compared to coal-fired power plants, the price for electricity generated by nuclear power plants is significantly cheaper for the consumer in most parts of the country.

—"But nuclear plants and their associated service facilities also have problems that must be addressed

- "Nuclear plants must be carefully designed, constructed, and operated so that none of the radioactive materials contained deep inside the plant can ever be released to the environment.
- "An independent Government agency (the Nuclear Regulatory Commission) regulates the safety of nuclear power plants at every stage.
- "A recent report by a group of safety experts has concluded that nuclear power plants are very safe (the chance of any member of the

FY 1977 Budget (ERDA)
R&D To Improve Commercial Use of Nuclear Power

Summary Table Research and Development Programs	(Outlays $ Millions) 1976	1977	% of change 1976–1977
Nuclear power plant safety*	60	89	49%
Safeguarding nuclear materials	15	27	80%
Nuclear fuel reuse	13	30	131%
Management of commercial wastes	12	63	425%
Total	100	209	109%

* Most of these funds are included in the budget of the Nuclear Regulatory Commission (NRC).

public being killed in a nuclear plant related accident is one in 5 billion which is slightly less likely than the chance of being struck by a meteor. And over 2000 times less likely than being struck by lightning).

- "The nuclear materials that serve as fuel for the power plant must be protected against theft.

* * * * *

- "Nuclear fuel discharged from power plants must be reused or recycled and radioactive waste material must be safely managed and disposed of."

* * * * *

Chief Programmatic Thrusts

Because Volume II of the Plan is designed to present programmatic efforts in considerable detail, the remaining section of this chapter concentrates on those broad areas critical to achieving energy goals. For most of the high-priority programs to be pursued in the near- and mid-term, these critical areas involve: (1) accelerating the market penetration of energy supply and conservation technologies in or entering commercial status; and (2) ensuring the environmental acceptability of these technologies (including health, safety, social, and aesthetic factors). For high-priority programs in the longer term, i.e., chiefly those for the essentially inexhaustible energy sources, the critical area is identifying and overcoming technical and environmental problems in the earlier research, development, and demonstration program phases.

In each of these two groups, the Plan considers:

- **The critical problems of each technology that prevent market penetration and environmental acceptability for the near-term and technological success for the longer term programs.** The former aspects of technology development tend to be the ones that have received the least attention in the past, are likely to pose the greatest hurdles to be overcome, and will require the closest coordination between the government and the private sector. Consequently, they receive more extended treatment in the technology discussions.
- **The strategic approach to be taken by the government—within the context of the Plan—and the larger, complementary role the private sector is expected to play.** Each technology requires a program designed to meet its particular development needs. As discussed in Chapter I, a government role is justified under selected conditions—e.g., when a low or uncertain level of private return on investment bars private action even though significant social (public) benefits could be achieved, or where the rate of implementation of the private sector would desirably be accelerated through assistance in addressing key uncertainties and/or institutional obstacles. If the Nation's overall efforts are to mesh effectively, each sector needs to understand the current approach to introducing the technologies and the roles expected of each.
- **The specific programmatic efforts being considered or already under way to implement the strategic approach.** In some areas, current efforts are extensive; in others, they are minimal in the expectation that normal market forces will cause the implementation of the technologies; and, in still others, efforts are contingent on interim results, further analysis, or negotiations between the government and private firms.

In the discussion that follows, the seven high-priority technologies becoming available in the near- and mid-term are addressed before the three longer term technologies. The order of presentation is:

1. Conservation
2. Light water reactors
3. Enhanced oil and gas recovery
4. Direct coal utilization
5. Synthetic fuels
6. Geothermal
7. Solar heating and cooling
8. Breeder reactors
9. Fusion
10. Solar electric

Additional detail on these and other Federal Technology efforts is presented in Volume II of this Plan being published separately.

Conservation Technologies

In the aggregate, conservation technologies—i.e., those permitting a more efficient use of energy—will contribute substantially to balancing the domestic energy supply and demand. ERDA–48 estimated that full implementation of more efficient technologies would permit continued economic growth without increased levels of imports through 1985; by the year 2000, such technologies would permit total energy consumption to be 25 percent less than it would be without their adoption (Scenario 1 of ERDA-48). Moreover, many of these technologies can have a more immediate—i.e., within 5 years—impact than those discussed later.

It must also be recognized that conservation technologies provide a potential cost-effective alternative to development of more supply technologies—i.e., in many instances, it will cost less to **save** a barrel of oil (e.g., through more energy efficient home heating) than it will to **develop** a new barrel of supply. This conclusion was suggested by the conservation scenarios of ERDA–48 (see Appendix B), which indicated that national energy needs could be met at lowest cost by employing improved efficiencies in

end-use. Although these scenarios were not able to reflect the costs of modifying end-use installations, the large difference in total costs among scenarios indicated that ample financial margin exists to cover these additional costs and still provide a low-cost solution. Moreover, the barrel saved will make more of the finite resource available for future needs.

Finally, these technologies generally will help meet energy needs with the least adverse impact on the environment. Specifically, as conservation actions reduce energy consumption levels, pollutant emissions and disruptions will be decreased because of reduced energy extraction and transportation activity, reduced fossil-fuel combustion, and the lessened need for disposal of waste heat and other materials. In addition, reduced energy consumption will extend the availability of fossil energy resources and allow time to develop technologies that use inexhaustible energy sources (e.g., solar, fusion, breeder reactors).

The advantages of conservation technologies are expressed generally above. The rate of application and introduction of conservation technologies in specific instances will be determined by the comparative economics and social acceptability of the available alternatives.

Many of these advantages were recognized in the recent enactment of the Energy Policy and Conservation Act. The stated purpose of the Act is to "reduce domestic energy consumption through the operation of specific voluntary and mandatory conservation programs."

The key conservation technologies under consideration differ significantly from supply technologies discussed later in this chapter. Specifically, their number, their diversity, and the relatively small energy contribution of any one preclude a single approach; rather, a broadly conceived strategy is needed. The nature of the conservation technologies ready for market penetration, the problems to be surmounted to gain adoption, and the broad-based strategy for facilitating their penetration of the market follow.

The Opportunities

The Nation has manifold opportunities for greater efficiency in the use of energy. Many are sufficiently developed to permit their rapid market penetration. They fall into four groups:

1. **Industry conservation.** The industrial sector currently consumes 40 percent of the Nation's energy. Reduction of this level of energy consumption will require a systematic evaluation of the industrial processes involved and a determination of those processes in which increases in thermodynamic efficiency can be achieved. Industry has made substantial progress in this regard, but more remains to be done. A host of more efficient technologies—some specific to individual industries and others applicable to many industries—is known. Many of these promise efficiency improvements of more than 30 percent. By implementing the successful results of RD&D, projected industrial energy consumption can be decreased by up to 17 percent per unit of output (equivalent to 1.8 to 2.7 million aggregate barrels of petroleum equivalents per day (BPDE) by 1985).

   Some of these more efficient technologies:
   - —Intermediate temperature heat pumps to minimize primary fuel consumption
   - —Brayton cycle turbine generators to produce electricity from the thermal discharge of furnaces (e.g., aluminum smelter or glass kiln)
   - —Heat transfer/thermal storage techniques to cascade energy flow within process industries
   - —High temperature insulation/refractories
   - —Waste heat recuperators and regenerators.
2. **Buildings conservation.** Commercial establishments and residential housing, which consume 29 percent of all energy in the U.S., present a number of opportunities to improve energy efficiency. Full understanding of these opportunities requires a systematic evaluation of essential factors associated with meeting a community energy needs. Three areas seem to hold large promise. First, a number of specific technologies exist—notably in insulation, shell design and heating, ventilating, and air conditioning—that need to be integrated and may require innovative marketing by industry to motivate consumers to accept and install them. Second, waste energy can be used more effectively in community systems. Third, some new technologies, such as the Annual Cycle Energy System,* appear promising but require further testing and/or development.

   Implementation of the results of these RD&D efforts could save 2.0 to 2.8 million BPDE by the year 1985.
3. **Transportation energy conservation.** The transportation sector, which consumes 31 percent of total U.S. energy, can reduce its petroleum consumption by using proven technologies and by implementing well-studied operational changes, including:
   - —Retrofitted aerodrag reduction devices on long-haul trucks

* **Annual Cycle Energy Systems (ACES) for Buildings.** A system potentially applicable to the residential and small commercial buildings market for space heating in winter and cooling in summer. Properly sized water storage tanks are incorporated in new building designs, including use of heat pumps. Heat is extracted from storage water in the winter; ice or chilled water in storage is used to cool in the summer.

—Reduced horsepower losses on accessory drive for autos and trucks
—Use of drag reduction devices between freight cars on trains
—New, energy-efficient engines for autos.

These improvements are expected to achieve savings of about 0.5–0.7 million BPDE by 1985.**

4. **Electric energy systems.** The electric utility sector presently uses about 27 percent*** of all U.S. energy consumed. This percentage is expected to increase substantially in the years ahead. Significant energy savings—expected to be 1.0–1.5 million BPDE by 1985—can be achieved by using improved equipment, and by altering consumption patterns, system structures and operations. Substantial capital and land savings and savings of oil can also be achieved. There are a number of opportunities for near-term savings, such as electric load management, application of energy storage, and removal of constraints to more efficient higher voltage transmission lines. A reliable electric energy system is also the critical link between advanced source technologies and end-use.

In addition to these opportunities, a continuing stream of new ideas and projects flows from the scientific community, individual inventors, and entrepreneurs. For example, recent private efforts have produced more efficient light sources and thermally activated heat pumps. Moreover, technological opportunities need to be considered in the light of alternative socio-economic-regulatory actions such as standards and innovative financing.

Market Barriers

By and large, most of these conservation technologies will have to overcome problems of economic, uncertainties, and normal resistance to the acceptance of new "products." Economic barriers will diminish as fuel prices rise and as more economical conservation technologies become available. For example, as fuel becomes relatively more expensive, end-users will be increasingly likely to invest in initially more expensive new technologies in the knowledge that **overall** (i.e., life-cycle) costs will be competitive for a given level of output. This "conversion" process will occur naturally but slowly within the market. In some instances the large, potential benefits may justify **government action in the form** of economic incentives or RD&D assistance.

** The savings envisioned are in addition to those currently being pursued by Detroit (e.g., lighter weight cars), but may be included by manufacturers in the efficiency improvements recently mandated by legislation.

*** This 27 percent is included ... the preceding three end-use sectors and is therefore nonadditive.

In addition to the economic barriers there are several other kinds that must be considered in mapping implementation strategies. Specifically, end-users may be reluctant to invest in new technologies because they do not know whether the technologies will perform as designed, or whether they will be reliable; developers and manufacturers are sometimes reluctant to create new technologies because they do not know whether they can, in an acceptable time frame, meet the institutional tests posed by state and local governments, lending institutions, unions, and other key groups whose support is required to implement new approaches in literally every segment of society. For example:

1. Most individuals and some industries are unaccustomed to using life-cycle costing as a basis for purchase decisions, and tend to make decisions on the basis of lowest initial cost. If companies continue to make investment decisions solely on the basis of initial cost, some new technologies (e.g., long-life light sources, and integrated appliances for mobile homes) will fail to realize full potential.
2. Personal taste and value are often wedded to existing technologies. For example, the changes in home appearance caused by the installation of solar heating may be an important deterrent to some prospective buyers, and the "look" of low drag automobiles and trucks may impede their acceptance by potential operators.
3. Vendors may be deterred from marketing a device because new and unexpected environmental standards might inhibit the use of a technology before the investment for development and marketing can be recovered.
4. Even though a basic technology is available, manufacturers may have to overcome numerous other technological hurdles and some institutional hurdles to adapt the technology to particular markets. This effort may greatly compound the economic uncertainties.
5. Potential users may be unsure whether the first generation of a technology will perform as advertised. The problem is accentuated where the available technologies have not been sufficiently demonstrated. Potential consumers cannot afford operating fuel-saving products at a loss, especially when no significant gain results from being the first operator of a new technology.

Finally, market penetration of conservation technologies may be impeded by a range of valid environmental, human health, and safety considerations. All new or modified energy related technologies must, of course, meet any existing pollution control requirements and many are required to meet new source performance standards. In improving energy efficiency in commercial establishments and

residential housing through improved insulation or reduced ventilation, for example, the potential hazards of increased exposure to fine particulates from insulation or the effects on human health of reduced ventilation must be evaluated.

In addition, exotic technologies and/or fuels producing electricity may produce some negative environmental impacts. For example, higher temperature combustion will substantially increase certain types of emission (expecially NO_x), higher temperature wastewater, and increase material deterioration. The use of certain fuels (e.g., nitrogen- and sulphur-bearing oils) in conjunction with high-temperature cycles will likely adversely affect air emissions.

On the positive side, quantification of the environmental benefits resulting from reduced energy consumption may help overcome institutional and social barriers impeding large-scale conservation.

Strategic Approach

In recognition of the need to address these general commercial and socioeconomic factors, the strategic approach to bringing a large number of conservation technologies into use in the near term incorporates five main elements:

1. **A national policy conducive to the adoption of energy-efficient technologies.** An element of this policy is the enactment of the Energy Policy and Conservation Act* which, in part, provides for:
   - —**A gradual removal of oil price controls,** to encourage normal workings of the marketplace —i.e., to increase supply and to reduce demand
   - —**Insuring the continuing progress in the improvement of automotive energy efficiencies,** to ensure consumer adoption of more energy efficient automotive technologies
   - —**The identification of areas for improving the energy efficiency of major household appliances,** to encourage consumers to make the most energy-efficient choices
   - —**Working with energy-intensive industries,** to encourage the adoption of existing conservation technologies
   - —**Federal conservation efforts,** to be carried out through procurement policies and through a 10-year plan relative to federally owned or leased buildings.
2. **A 0- to 5-year planning horizon.** In addition to the near- (1985), mid- (1985–2000), and long-term (post 2000) planning horizons established by ERDA's enabling legislation, a new planning horizon—0 to 5 years—will be included in the annual energy RD&D Plan. Opportunities in nuclear, fossil, solar, and other technical areas will be included, although the predominant opportunities will probably be in the conservation program. Fuel substitution opportunities also will be sought because of the beneficial impact on oil imports and relief of gas shortages. This 5-year focus is intended to roll forward each year. The process will be institutionalized and monitored for successes and failures. The results of the initial ERDA review will be coordinated with other interested agencies, particularly FEA, to ensure a proper overall governmental approach is being designed and the best opportunities are being identified. Industry views will also be sought in this design phase to ensure that any government action assists and provides incentives to industry rather than result in preemptive, unneeded, or irrelevant government action.

   Although some of these technological improvements will begin to appear in the marketplace between now and 1980, it may be cost effective for government to assist industry in accelerating their introduction and acceptance by the American public.
3. **Accelerated identification of promising technologies (particularly within the 5-year horizon) and dissemination of information about their application in potential end-users.** For some time, FEA has had a program to identify conservation opportunities in industry, buildings, and transportation. Other involved agencies include the Cooperative Extension Service, Department of Commerce and Housing and Urban Development.
4. **Integration of market and institutional barriers into the plans for developing the most attractive conservation technologies and for facilitating their implementation.** A general approach is being developed to consider implementation barriers at the inception and throughout the RD&D planning process. (See Chapter V.)
5. **Demonstration programs to work out the implementation details of more complex technological approaches.** Such efforts will most likely be needed in the highly fragmented building industry. Leading candidates for such programs include the Annual Cycle Energy System, integrated housing, and community energy systems. Similarly, demonstrations of conservation technologies with broad industrial applicability may be justified. The appropriate government role in this area will be determined by further analysis of promising technologies and by socioeconomic research that diagnose barriers and the cost effectiveness of alternative approaches to overcoming them.

Action Program

The principal elements of a Federal program to carry out the strategy outlined above include:

- Carrying out the provisions of the Energy Policy

* Public Law 94–163.

Conservation Act within Federal Energy Administration, and the Department of Commerce
- Encouraging the private sector to implement conservation and fuel-substitution technologies within the 5-year planning horizon
- Establishing a joint FEA and ERDA planning and implementation capability
- Developing a capability for:
  - —Identifying the energy-savings technologies that are attractive from the point of view of cost and implementation
  - —Developing energy-consumption standards
  - —Identifying environmental costs and benefits
  - —Verifying technology capabilities
  - —Informing end-users about new technologies
  - —Identifying and assisting in removing institutional obstacles
- Carrying out demonstration programs as appropriate.

Light Water Reactors

Although forecasts vary, most show nuclear power as a major factor in meeting U.S. energy needs by the end of this century. A typical forecast is for an installed nuclear capacity building from the present level of 39.6 millions of kilowatts of capacity (gigawatts—GWe) to 70–76 GWe by 1980, increasing to 160–185 GWe by 1985, 265–340 GWe by 1990, and 450–800 GWe by 2000.*

Industry and Government, in cooperation, have brought light water power reactors to their current status of safety and economic viability. As a result, this energy source presently supplies some 8 percent of U.S. electricity demand. Although several problems impede rapid market penetration (e.g., long lead times; evolving regulatory requirements; less than desired plant reliability and availability, a feature also shared with large coal plants, and high capital cost **), over 200 nuclear power plants have now been committed or ordered.

To bring the technology of light water reactors to full economic fruition several parts of the fuel cycle must be validated—technically, commercially and environmentally. In brief, the areas requiring increased emphasis are:
- Better definition (i.e., in terms of location, grade, extent, economics and availability) of recoverable domestic uranium resources

* Includes up to 60-80 GWe of breeders, assuming successful completion of the breeder development program.

** Despite higher capital costs, nuclear energy's lower fuel costs (compared with fossil fuels) allow power to be produced at a lower **total** cost in **most** of the Nation. Only in those areas of the West where abundant, low sulphur coal reserves can be mined cheaply is nuclear power not currently competitive. Of course such estimates depend on the accuracy of future estimates of both nuclear and coal costs.

Table III–7

Cut Off Cost*	Reserves**	Potential	Total
10	315,000	1,000,000	1,315,000
15	420,000	1,620,000	2,040,000
30	600,000	2,900,000	3,500,000

* Recovery cost per pound.
** In addition, 90,000 tons of by-product is expected through 2000.

- Success in the transfer of responsibility for uranium enrichment to private industry and progress in initiating new U.S. capacity to meet future U.S. and overseas demand for enrichment services
- A commercial fuel reprocessing and recycling capacity
- Demonstrated safe and environmentally acceptable waste treatment and storage and disposal processes and facilities
- Improved LWR technology
- Strengthened safeguards.

Uranium Resources

If the use of light water reactors using domestic uranium resources is to expand as projected, an increase in the domestic uranium resources must also take place. Although uncertainties about the extent of uranium and the economics of its recovery exist, ERDA's present assessment (see Table III-7, above) is that the reserve base is adequate to provide for all operating and planned power reactors (235,000 MWe) and to permit further growth even without the recycling of plutonium and uranium. However currently identified economic-grade ($30 or less per pound production cost) uranium resources may be inadequate to support the postulated long-term expansion of light water reactors beyond 1990 for their lifetime. Thus, additional major quantities of uranium resources of all grades must be identified and developed into reserves.

Uranium Resources—Tons of Uranium Oxide (U_3O_8)

The necessary industrial commitment to exploration and expansion of production capacity to ensure adequate development of resources has been retarded. To identify areas favorable for uranium exploration, to assess more completely the resource base, and to improve exploration and extraction technology, a comprehensive government program, National Uranium Resource Evaluation (NURE) has been in progress for about 2 years. Under ERDA's direction, it is designed to provide a systematic and extensive survey of the conterminous U.S. and Alaska by FY 1981. NURE is expected to identify localities that appear favorable for detailed exploration

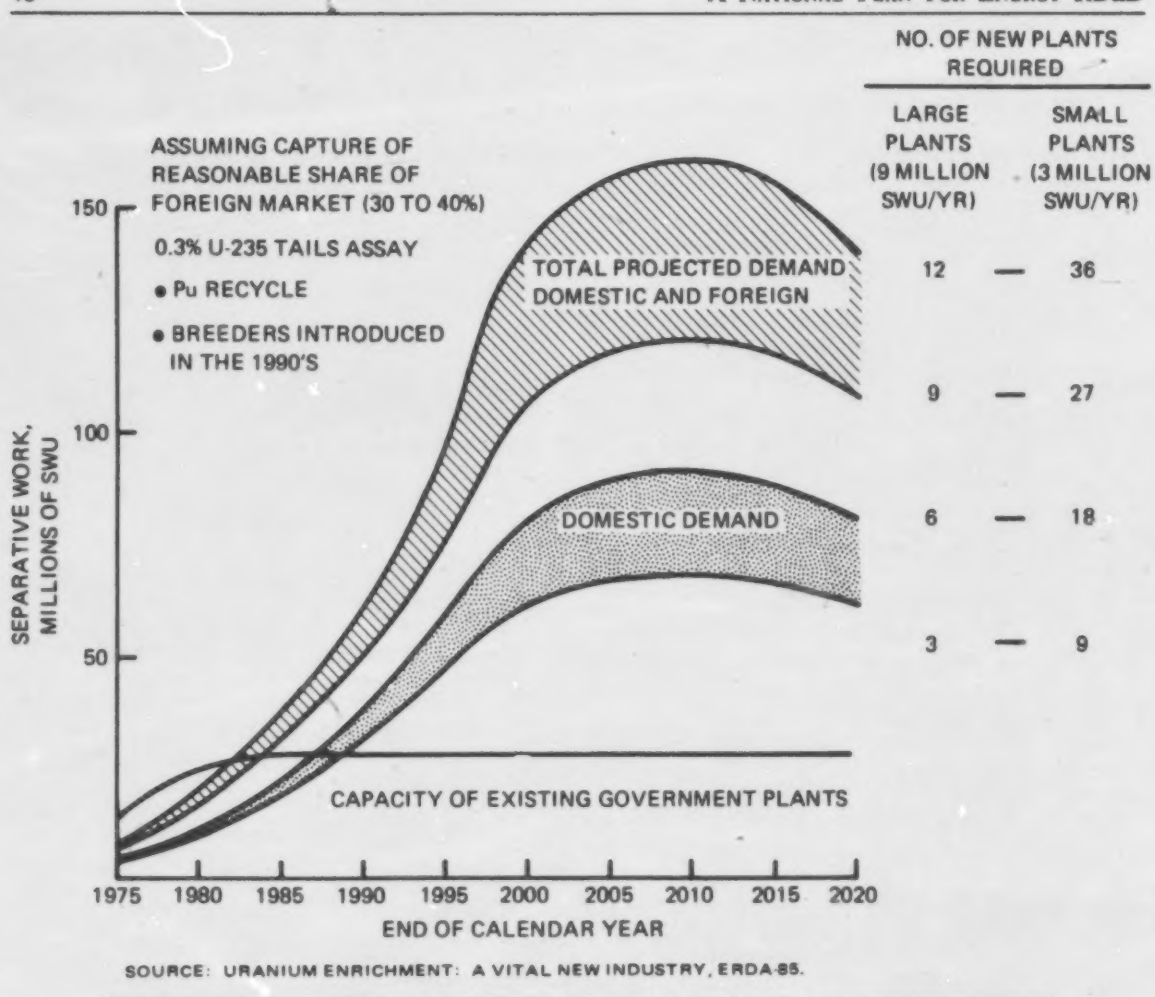

NO. OF NEW PLANTS REQUIRED
LARGE PLANTS (9 MILLION SWU/YR)
SMALL PLANTS (3 MILLION SWU/YR)
ASSUMING CAPTURE OF REASONABLE SHARE OF FOREIGN MARKET (30 TO 40%)
0.3% U-235 TAILS ASSAY
• Pu RECYCLE
• BREEDERS INTRODUCED IN THE 1990'S
TOTAL PROJECTED DEMAND DOMESTIC AND FOREIGN
DOMESTIC DEMAND
CAPACITY OF EXISTING GOVERNMENT PLANTS
SEPARATIVE WORK, MILLIONS OF SWU
150
100
50
12 — 36
9 — 27
6 — 18
3 — 9
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
END OF CALENDAR YEAR
SOURCE: URANIUM ENRICHMENT: A VITAL NEW INDUSTRY, ERDA-85.

Figure III–2 Annual Demand for U.S. Separative Work

and to provide an initial estimate of the resources in such localities. Such information will support private industry exploration and will provide a more comprehensive basis for estimating the potential uranium resources that may be available in future years. It is expected that the uranium production industry will continue to take responsibility for assuring the transferral of identified uranium resources to production capacity and for the establishment of relationships between buyers and sellers that will guarantee that uranium demands will be met. ERDA will also continue to analyze the industrial capability to produce uranium at needed rates.

Uranium Enrichment

Light water reactor technology depends on separating the small fraction (0.7 percent) of natural uranium that is fissile (i.e., will fission when struck by a neutron) from the much larger mass of nonfissile natural uranium. Uranium used as a fuel must be enriched by increasing the concentration of uranium-235, the fissile isotope.

During and subsequent to World War II, the government built three large enrichment plants that use the gaseous diffusion process to enrich uranium. These plants will produce about 15 million separative work units (SWUs)* this year for both foreign and domestic use, which would be sufficient for about 150 nuclear power plants of 1000 MWe each. The capacity of the existing ERDA gaseous diffusion plants will be improved and electrically uprated to a capacity of approximately 28 million SWUs by 1981, which should meet the long-term enrichment

* Separative work units are a measure of the effort required to enrich the uranium fed to the enrichment plant.

services requirements for reactors planned through about 1984. However, by 2000, projected domestic and foreign nuclear power expansion could require as many as 15 additional 9 million SWU enriching plants depending on the tails assay, the introduction date of Pu recycle, and the level of enriching services sales to foreign markets. (See Figure III-2.)

ERDA believes that expansion of uranium enrichment is a business operation best carried out in the private sector. To this end, over the past few years, ERDA has been transferring uranium enrichment technology to a number of qualified domestic industrial firms. But several factors have inhibited the private sector's moving ahead quickly in this area. First, enrichment plants require enormous investments—about $3 billion for each full-scale plant—and long return-on-investment lead times. Second, the technological competition between the diffusion process and the centrifuge method creates an element of technical and financial uncertainty. Although gaseous diffusion is an established technology with a demonstrated reliability greater than 99 percent, gas centrifugation might prove to be more economical. In addition, there is another process, laser isotope separation, whose technology has yet to be demonstrated.

To enable and encourage the private sector to begin the necessary investment to expand enrichment capacity, the Nuclear Fuel Assurance Act, was proposed to Congress in June 1975. This Act will provide ERDA necessary authority to negotiate cooperative agreements with private firms, which, after Congressional approval, would provide temporary financial assurances to these private firms. Specifically, ERDA is seeking authority to enter into contracts for cooperative agreements up to the amount of $8 billion to assure that in the unlikely event the proposed private ventures do not succeed, the government could still take actions to ensure that the plants would be brought on-line in time to supply domestic and foreign customers with uranium enrichment services when needed. It is expected that none of these funds would have to be expended for the assumption of private ventures. In addition, the legislation provides for a backup plan for a new government-owned facility at its Portsmouth, Ohio, site as a contingency measure in the event that private ventures are unable to proceed. When private industry efforts have made sufficient progress, the backup plan will be dropped.

Reprocessing and Recycling Capacity

Fuel elements discharged from light water reactors contain about half the fissile material present in new fuel elements. From economic and conservation points of view, recovery and reuse of the materials appear desirable, but no domestic or foreign commercial facilities currently process spent fuel from commercial reactors. The first domestic commercial plant experienced some operational and maintenance difficulties and was shut down for modification and expansion; restart before 1982–1983 is not foreseen. A second plant has not reached—and may never reach—the operational stage. A third commercial reprocessing plant was expected to commence operation in 1976, but will be delayed pending construction of facilities to satisfy new criteria for waste treatment and plutonium shipment. It would appear that, before any new commercial fuel refabrication plant that depends on large-scale utilization of plutonium can be fully licensed, a decision on the General Environmental Statement on Mixed Oxide Fuel (GESMO) must be forthcoming. A final statement by the Nuclear Regulatory Commission (NRC) is expected in 1977.

From a resource standpoint the development of a commercial reprocessing and recycling capacity is highly desirable for the continued growth of nuclear power. The continued absence of a reprocessing and recycling capability will materially increase the demands for uranium, increase enrichment capacity requirements, and necessitate interim storage of large volumes of spent fuel elements.

ERDA is proceeding with a program to assist industry to resolve outstanding problems associated with LWR fuel reprocessing and recycling. Initial program efforts (i.e., those to be completed during 1976–1977) include:

- Solicitation of expressions of interest and information from the nuclear industry on impediments to commercialization faced by industry and suggestions on what steps by industry or actions by ERDA could overcome these impediments.
- Based on industry response, other studies and evaluations, and discussions with industry and other government agencies, a specific plan of action will be formulated. If necessary, legislation for any required assistance would be drafted and submitted for Congressional approval.
- A broadly based program of research and development of the chemical processes, systems, and components applicable to the final phases of the LWR fuel cycle will be pursued concurrently. Areas requiring additional development include the process technology, systems operations and maintenance, design concepts and understanding of environmental impacts.

Radioactive Waste Management

A safe and environmentally acceptable program for the management and control of radioactive wastes is essential. Central to this waste management program is ERDA's acceptance of the responsibility for the custody of those radioactive wastes that have been identified by the NRC as

requiring long-term federal control for reasons of human health and safety. The realization of nuclear power's full potential can only occur if environmentally safe waste disposal methods are developed.

Of the various radioactive wastes produced, most of the radioactivity is concentrated in one of the waste streams from the chemical processing of spent nuclear reactor fuel to recover its residual potential energy sources. This high-level liquid radioactive waste, as defined in NRC regulations, may be stored no more than 5 years after the processing of the parent fuel, and the stable, solidified product, sealed in high-integrity containers, must be delivered to ERDA no more than 10 years after processing the fuel. The very long-term potential hazard of high-level waste is from its content of plutonium-239 and related materials (known collectively as transuranium nuclides). Transuranium waste will also be generated in plutonium recycle facilities and a proposed NRC regulation would require that transuranium-contaminated waste, converted to solid form if necessary, be transferred to ERDA no more than 5 years after its generation.

These wastes need to be isolated from man's environment for extremely long periods of time. The preferred solution appears to lie in emplacing the relatively small volumes of these potentially hazardous radioactive wastes within deep, stable geologic formations. (Some geological formations have been stable for hundreds of millions of years, and there is every reason to believe they will continue to be so for further geological periods. Studies to date of a prehistoric underground natural nuclear criticality in what is now Gabon, indicate the radioactive residues of the phenomenon—natural high-level waste—have remained essentially at the generation site for well over 1 billion years.)

Laboratory and theoretical studies of geologic isolation of waste have been in progress for 20 years, and site investigations are now being conducted in southeastern New Mexico. A potential application for this location, beyond its use as a pilot plant, would be storage of transuranium waste generated by ERDA in its military production operations. In addition, it would also provide a facility for limited experiments with commercial high-level waste, beginning in the mid-1980's. However, demonstration of geologic emplacement or storage of high-level waste on a much larger scale is essential. The timing is propitious to undertake a major program to develop sites in several sections of the Nation in several different types of geological formations. This expanded effort would facilitate waste management on a regional basis, including the involvement of knowledgeable state government and university scientists.

In geologic isolation of waste, the geological medium itself provides one of the primary safety factors. The form of the waste and its container provide additional safety factors. In earlier stages, when the waste is still in retrievable storage or in transit, the physical and chemical forms of the waste may affect the margin of safety available in case of container rupture, however unlikely that might be. A development program aimed at less soluble, more monolithic waste forms has been underway for some time. Primary emphasis has been given to the silicate glass form.

Another program, begun in 1972, concerns retrievable surface storage of commercial, solidified, high-level waste at a central federal site. The draft environmental impact statement published by the former AEC in September 1974, which was a key step in proceeding to the location, detailed design, and construction of such a repository, was criticized for lack of detail in its discussion of the follow-on ultimate disposal of waste, and for failure to discuss regulatory issues. Pending issue of one or more generic environmental impact statements to replace the previous draft, retrievable surface repository work is being deferred. In view of the delays in generating commercial high-level waste and the planned acceleration of the geologic site development program, ERDA now believes that the eventual need for a surface storage facility will be much less than was thought when development started. ERDA's present plans are to begin demonstration of the terminal (geologic) storage of commercial high-level waste by the early to mid-1980's. Since criteria for waste forms and packaging will affect processes, facilities, and economics of the commercial fuel cycle, ERDA has a goal of establishing (or recommending to NRC) such criteria by the end of 1978.

LWR Technology

In addition to the critical need to establish a complete fuel cycle, a number of lesser problems impede full development of nuclear power. These include less-than-desired plant availability and reliability, long construction and licensing lead time, and evolving regulatory requirements.

If the level of availability and use of nuclear plants improved, it would translate directly into savings of fossil fuel—e.g., the daily output of a 1000-MWe LWR is equivalent to approximately 30,000 barrels of oil. Cost savings from realistically attainable construction time and design standardization/modularization could be on the order of $1–$3 billion during 1980–1985.

Although the solutions to these problems lie in the industrial/utility sector, the amount of effort being devoted to them by industry is not yet commensurate with the potential economic benefit to the public or reduction in oil consumption. Governmental analysis and planning could identify ap-

proaches to stimulating private investment in this area.

Specifically, ERDA is undertaking a program to stimulate greater industrial involvement in improving existing LWR technology and techniques. This program will include component testing and support in the basic technologies required by industry to increase the availability and productivity of existing plants. Determination of the underlying causes of plant deratings will be sought. These efforts should result in improved component reliability and in a reduction of scheduled and unscheduled downtime. The program will also seek to reduce the time and cost of new plant construction through such efforts as engineering standard support, standardization/modularization design studies, improved construction technology development, and special siting studies. The efforts will be conducted with industry and utility groups, and will be closely coordinated with other interested government agencies, including NRC and FEA.

Safeguards

The potential for sabotaging facilities or stealing and diverting fissile materials raises a fundamental safety issue. Unless the public fears concerning these issues can be allayed, future expansion of the nuclear power industry is likely to be curtailed.

The question of the degree of protection to be afforded nuclear facilities to prevent criminal diversion of materials or other criminal acts that could constitute a public safety threat continues to receive substantial government attention. In addition to NRC's establishing appropriate safeguards criteria for commercial nuclear facilities, ERDA is supporting a program of research and development on more effective safeguards systems and physical protection measures.

All facilities to be constructed and operated under cooperative demonstration programs will include the demonstration of appropriate safeguards systems and measures. To implement this policy, ERDA, for example, is currently supporting the development of a conceptual design that will identify performance requirements for the various parts of the physical protection system, the accountability system, and the materials control systems. Such information can then be integrated into the detailed design of future fuel cycle facilities.

Enhanced Oil and Gas Recovery Techniques

From past exploration, approximately 290 billion barrels of conventional oil, 130 billion barrels of heavy oil and bitumen, and 600 trillion cubic feet of natural gas are known to exist but cannot be recovered with present commercial recovery techniques. Enhanced oil and gas recovery techniques might eventually recover 40 billion barrels of this oil and 250 trillion cubic feet of the natural gas, or the equivalent of 10 to 12 times current annual production levels.* If costs of the recovered oil and gas were competitive with alternative fuel sources, enhanced-recovery techniques could postpone the expected domestic oil and gas production decline by a decade or more.

Enhanced recovery is a generic term for a variety of techniques for increasing the flow of oil and gas from their natural locations in permeable rock to producing wells and for increasing recoverability of the resources. The individual techniques, which have different applications in different reservoir formations, are at various stages of development; if proven successful and marketed, they would permit greater recovery not only from existing declining fields but also from new fields under development. Present high priority areas are inland.

Implementation Barriers

A number of techniques for enhancing the recovery of oil and gas are being researched and tested by private oil and gas companies, and, eventually, industry would undoubtedly develop and implement these technologies on its own. However, because of current economic circumstances, private industry might pursue alternative investment opportunities, thus postponing development and marketing of enhancement techniques.

Indeed, enhanced recovery techniques require significantly larger capital investments than conventional secondary recovery. Specifically, the estimated cost of oil using several of the enhanced oil recovery methods now being tested exceeds current domestic oil prices; however, this situation may become more favorable as oil prices are decontrolled over the coming years.

Not only is industry hampered by uncertainty over such institutional barriers as price regulations and tax requirements, but the possibility of antitrust action has tended to limit cooperaive ventures that could spread the risk and increase the support base.

Environmental problems are principally the same as those associated with primary production. However, tertiary oil recovery techniques may affect geological substructures differently. Secondary and tertiary methods, which will be used to stimulate existing wells, could cause contamination of ground water through pipe casing leaks—a problem similar to that which now exists for primary drilling—

* The estimate of potential oil recovery is ERDA's, based on a range of industry estimates. The gas recovery estimate is based on the **Natural Gas Survey, Volume II**, U.S. Federal Power Commission, 1973.

as well as through geologic faults. Biological concerns include what impacts waste heat and dissolved and suspended solids may have on aquifers. In addition, enhancement techniques for oil recovery may result in gaseous emissions of H_2S.

Strategic Approach

The Plan anticipates that the enhanced recovery techniques will be developed primarily and applied commercially by industry as its ability to predict returns on a project improves and in response to rising domestic and international oil prices. This process may be accelerated by complementary Federal efforts to address production, market, and environmental uncertainties. The Federal program is intended to provide more quickly an understanding of the magnitude of the recoverable resources; evaluation of the real potential of alternative technologies; understanding of the environmental impacts; and, ultimately, more complete recovery of the reserves.

The earlier various enhanced recovery techniques are researched and developed, the faster reasonable estimates of actual additional recoverable resources can be developed as input to substantive planning, development of national energy strategy, and the setting of priorities.

Development and commercial application of enhanced recovery techniques requires several years for evaluating the necessary technology, the potential environmental impacts, and the attendant economics. For example, 5–6 years may elapse between project initiation and resultant production; several more years may pass before profitability and extent of environmental impact can be demonstrated. Thus, research on resolving the uncertainties associated with advanced technologies needs to be intensified.

The availability of economical enhanced recovery techniques might result in more complete, ultimate recovery of reserves. More complete recovery might result from changes in the current production cycle from primary recovery to the various phases of enhanced recovery. For example, further research might obviate the need for the traditional primary—secondary—tertiary cycle indicating that in certain instances water flooding (secondary recovery) should be omitted and replaced by micellar-polymer flooding (tertiary recovery), and that water flooding should be done concurrently with primary production. Such advanced technology application might replace the "last ditch" applications that often have marginal economic returns.

The costs and benefits of various enhanced recovery techniques are being analyzed by ERDA to determine the appropriate mix and level of Federal R&D expenditures.

Action Program

The Government is developing an approach to accelerate the development and application of enhanced-recovery techniques:

- ERDA is co-funding research, development, and demonstration projects with industrial firms.
- ERDA is analyzing and interpreting field test results to understand the potential for the profitable use of certain enhanced-recovery techniques.
- FEA is reviewing price regulations, tax requirements, and other institutional barriers relative to enhanced-recovery.

Under jointly funded Federal RD&D projects, private firms provide an average of 60 percent of the funds. However, as the risks become lower the Federal role should be reduced. Each of the projects involves a field demonstration, which is expected to produce technical, economic, and environmental results that will be transferred to other firms in the industry to obtain maximum benefit. Presently, 15 major enhanced-recovery demonstrations are under way. These demonstrations are split between enhanced oil recovery (approximately 55 percent) and enhanced gas recovery (45 percent). Additional demonstrations are anticipated for FY 1976, with about the same split between oil and gas recovery efforts. Environmental factors are considered in developing and executing this demonstration program.

The legal and institutional questions are being investigated by the FEA, which implements the price regulations. FEA is also evaluating applicable tax laws to determine if reasonable changes can be made to encourage enhancement projects. Reduction of uncertainty over oil price legislation might speed industrial activity since the economics of the various advanced technologies for enhanced recovery are very sensitive to price. A clear-cut explanation of how output from enhanced recovery techniques will be priced and how the large accompanying research and development expenses will be treated for tax purposes could serve as an incentive for initiating major projects.

Direct Utilization of Coal

Although the Nation's coal resources are not inexhaustible, they do represent one of the Nation's most abundant fuel resources. At present, coal is supplying only 17 percent of domestic energy. At that rate of consumption, known reserves economically recoverable in a 1970s competitive environment would last more than 300 years. As prices of alternate fuels escalates in the future, less accessible coal reserves will become increasingly attractive. Thus, coal's economic usefulness should continue well into the 21st Century and perhaps beyond.

Production of coal is now beginning to grow again and reached 640 million tons in 1975, exceeding the 400- to 600-million tons-per-year range that had persisted since World War II. Indeed, several forecasts project a tripling of domestic demand by the year 2000, provide barriers to such high levels of use can be overcome. Currently, about 65 percent of the coal is used in central station electricity generation; about 15 per cent, as coke; and most of the remaining 20 percent, in industrial plants for power or process heat. Consequently, in considering how to increase the use of coal, interest centers first on application in central station power plants and second, in industry.

Implementation Barriers

Immediate expansion in the use of coal is limited by the high costs and uncertainties associated with the environmental acceptability of this energy source. The critical environmental concerns are twofold.

First, much of the coal can best be extracted through strip mining. This will require restoring the land to original productivity and recontouring. The necessary revegetation would consume substantial amounts of water, a commodity in short supply in western regions where much of the strip mining would occur. Moreover, if stripping were indiscriminate, disrupted habitats could endanger wildlife species and upset ecological balances. In some areas, coal extraction threatens aquifers which lie above or in a coal seam.

Given these problems, research must be continued on restoration of productivity. The reclamation effort itself will have some impact on water quality and quantity. Acid and alkaline leaching into ground and surface waters will occur before strip-mined land can be fully reclaimed. Wind/water erosion can also deteriorate water quality by increasing sediment loads. Thus, prompt reclamation efforts, even as mining continues elsewhere at the extraction site, needs to be instituted to reduce this potential for erosion, soil loss, and water contamination.

The second environmental concern is the problem associated with stack effluents. Central station operations generate such atmospheric pollutants as noncombustible residuals (ash), and noxious gases, Existing technology can remove the ash satisfactorily, and the cost of the necessary equipment to do so has been incorporated fully in utility rate bases. Fly ash systems developed for the utilities by industry during the last several decades are now standard equipment on new power plants.

The discharge of noxious gases (oxides of nitrogen and sulfur) has become a concern only in the relatively recent past and, as a consequence, control of this pollutant is not as well in hand. Nitrogen oxide emissions can be controlled by controlling combustion temperatures through techniques such as staged combustion, or flue gas recirculation. Moreover, this technique can achieve EPA discharge levels of 0.7 pounds of NO_x per 10^6 Btu at a cost close to that of conventional combustion systems. It is expected that industries will adopt this technique.

Nitrogen and sulfur oxide emissions may degrade air quality in the vicinity of the emission source beyond allowable levels. In addition, sulfate transport over long distances is a concern. An EPA regulation forbids more than 1.2 pounds of sulfur dioxide per 10^6 Btus, which is achievable by burning low-sulfur fuels. However, because supplies of low-sulfur fuels are limited, it will be necessary to employ sulfur-removal systems to permit use of fuels with a higher sulfur content.

In addition to the environmental problems, rapid development of extraction sites in the Northern Great Plains and the Rocky Mountains will bring large outside populations to remote and sparsely populated regions. This influx may create a sudden, heavy demand for such necessities as housing, schools and health care facilities, needs which small communities may have neither the capability nor the money to respond to. On the other hand, many regions might profit from the increased activity.

Strategic Approach

Private corporations, government and industry organizations, such as Electric Power Research Institute (EPRI) have been involved in developing approaches to improve technologies for the direct utilization of coal. Major private sector R&D efforts are ongoing with regard to coal utilization technologies. It is expected that industry will have a continued high interest in developing and implementing these technologies. The government role is to identify those aspects of coal utilization that have high potential payoffs to society, but are not receiving adequate attention or funding. Furthermore, the government has a role in disseminating information and providing financial incentives (where necessary), in order to facilitate market penetration of near commercial technologies.

The strategic approach to be undertaken addresses mining and air pollution problems separately. In the extraction area, improvements in mining techniques and equipment are under investigation to increase both the recoverable fraction (leaving less unmined coal in the ground) and the efficiency of extraction so that fewer man-hours and less energy is expended per ton of coal mined.

Environmentally acceptable methods of land reclamation are also being developed to restore

mined areas to an acceptable condition with equal or superior productivity. Simultaneously, improved miner health and safety are being sought, especially in underground coal mines.

To deal with the problem of complying with air pollution standards, coal can be cleaned in advance of combustion, sulfur can be removed during combustion, or sulfur can be removed from stack gases.

Removing sulfur from coal with various mechanical or chemical separation techniques in advance of combustion or conversion reduces problems of on-site waste disposal; allows use of existing coal combustion systems; and may improve the economics of use and transportation (compared to raw coal). Coal cleaned in this manner can be further enhanced by crushing and blending to uniform size and Btu value, in order to improve its operability and reliability. One disadvantage of this process is the loss of some of the coal due to imperfect separation. Government and industry groups such as EPRI have been developing such improved benefication methods. ERDA is monitoring and utilizing results of these efforts to perform economic trade-off studies and analyses in order to promote their use and adoption by private industry.

Substantial effort is being devoted to removing sulfur pollutants during combustion. One promising process is the fluid bed combustion system in which the coal is burned in a solid/air mixture, with the solid including a substantial quantity of limestone. Combustion temperatures are lower, which aids in controlling nitrogen oxide emissions. The sulfur is converted to a dry calcium sulphate. The cost has been estimated (but not yet demonstrated) as being comparable to that of scrubbers. In addition, fluid bed combustion systems do not have the plant-efficiency penalty of scrubbers.

Other advanced technologies with potentially attractive environmental features in terms of air pollution include coal gasification in combined cycle systems and MHD. Direct use of coal in industry (as opposed to use in an electric utility that generates electrical power used by industry) faces a more complex set of problems. Frequently, scrubbers, the most immediately available air pollution control solution for large central stations, are uneconomical for smaller scale industrial applications. It is principally the operating and maintenance costs of the add-on scrubber systems that discourage such application. Consequently, fluidized beds, which eliminate the need for add-on systems, appear to be the more attractive solution.

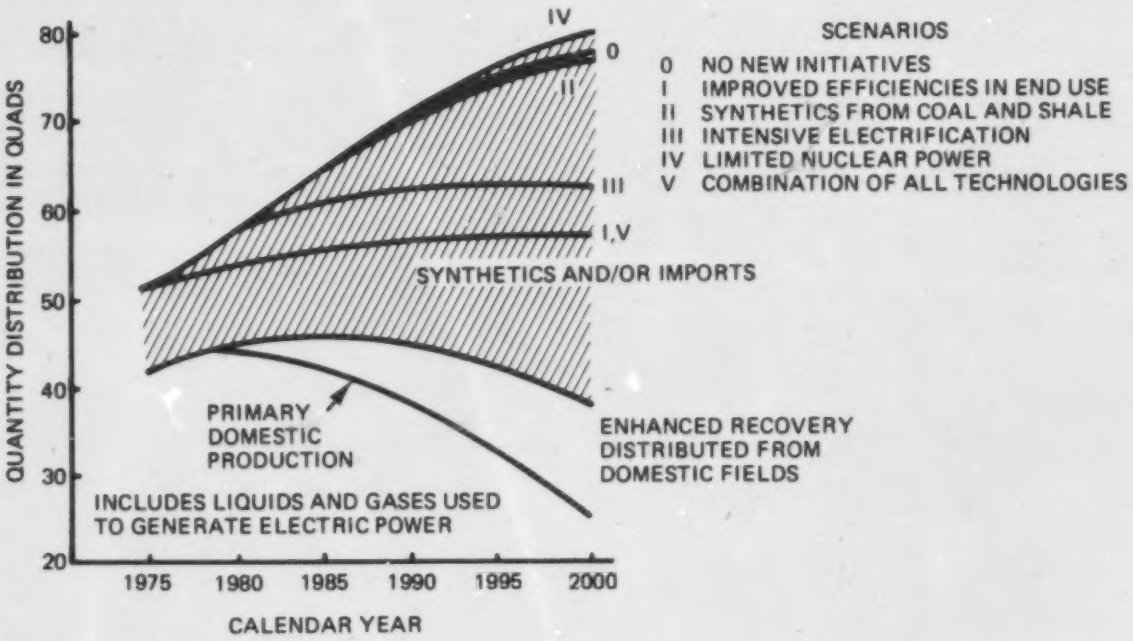
In addition, large, central power stations could use low-sulphur coal in conjunction with stack gas scrubbing systems, which have reached the stage of limited commercial application. However, even though these systems meet immediate requirements, their commercial reliability has not yet been fully demonstrated. Furthermore, the sludge-like gypsum formed in the process is difficult to dispose of and nearly doubles the bulk of the waste from a power station. Scrubbers may increase the cost of central stations by about 20 percent and reduce station efficiency. Consequently, the Plan provides for developing alternative air pollution control means that reduce the total disposal problem and increase the pollutant removal capacity of the central stations.

In addition to the above technologies for using coal directly, it may be possible to substitute to some extent coal for oil in **oil-burning** equipment used by utilities. Finely pulverized coal suspended in fuel oil can possibly be accommodated by minor modifications of existing burner and fuel-handling equipment. For a given heat rate, the fuel oil demand may be reduced as much as 30 percent. As might be expected, the air pollution problems for both fuels are NO_x and SO_x, and particulates. Because of the utility industry's large investment in existing oil-burning equipment, retrofitting to permit an oil-coal slurry could simultaneously result in lowering petroleum demand and increasing coal consumption. The economics and practicality of this approach are being investigated.

Action Program

By 1985, the Department of the Interior's Bureau of Mines (BOM) will have completed major demonstrations in the eastern, central, and southwestern sections of the country to establish the economic efficacy of integrated extraction-reclamation systems. The Department also has a health and safety program to address related issues. In addition the BOM and the EPA are developing improved coal treatment technology to upgrade the quality of coal by reducing the amount of ash, sulfur, and other constituents.

The cleaning of flue gases from coal-fired utility and industrial boilers—i.e., scrubbing—has been assigned highest priority within the EPA-coordinated Federal Interagency Environmental Control Technology R&D Program. To this end, EPA is developing second-generation Flue Gas Desulphurization (FGD) systems that offer improved economics and reliability and reduce the amount of by-products that must be disposed of. A comprehensive sludge disposal technology program supplements the second generation work. In a parallel program, EPA is pursuing flue gas treatment to develop a cost-effective process for full-scale control of nitrogen oxide. Fuel additives, which will serve the same purpose as sulfur in enhancing electrostatic precipitator performance, are under study and development. And advanced particulate control technology is undergoing development to broaden applicability and effectiveness.



SOURCE: ERDA-48, 1975.

Figure III–3 Projected Demand for Liquids and Gases to be Met by Synthetic Fuels

ERDA is developing advanced power systems which will permit power generation from direct firing of coal and coal derived fuels in an efficient and environmentally acceptable manner. ERDA's research includes the use of open and closed cycle gas turbines in combustion with advanced combustion and gasification technologies, such as atmospheric and pressurized fluidized bed combustors. The fluidized bed combustors offer the major advantage of internal removal of sulfur oxides from combustion products. This approach offers the potential for eliminating the need for stack gas scrubbers; required in conventional coal-fired boilers to meet emission standards. In addition to research units which have been operated by ERDA and EPA for several years, there is currently under consideration an atmospheric fluidized bed pilot plant.

Synthetic Liquid and Gaseous Fuels

The absolute demand for oil and gas, even under optimistic energy-conservation assumptions, will outstrip the supply provided by conventional domestic oil and gas sources, thus increasing the level of oil and gas imports. Moreover, the gap between the demand and domestic production is widening. Therefore, in the years ahead, the U.S. must seek to exploit untapped domestic oil and gas sources and must develop alternative energy sources to minimize its dependence on energy imports.

Over the next 25 years, synthetic fuels* offer a domestic energy alternative to imported oil and natural gas. For this option to be credible, however, under the most favorable energy-conservation assumptions and enhanced domestic oil and gas recovery techniques, approximately 5 million barrels per day equivalent synthetic production capacity must be operational by 1995 to hold imports at current levels (or about 6 million barrels per day). (See Figure III–3.) Under less favorable assumptions, the need for synthetic fuels could be twice this amount or more.

Implementation Barriers

Although not in commercial use in the U.S., technological processes for converting coal to clean liquid and gaseous fuels—e.g., Lurgi gasification, Fischer-Tropsch synthesis, and Koppers-Totzec—have been available for many years. However, given the present cost and the uncertain relative economics of synthetic fuel production cost, it is not surprising that a synthetic fuels industry has not recently been developed in the U.S. by the private sector. Commer-

* That is, the clean liquid and gaseous fuels produced from converting coal and shale.

cial size plants—i.e., those with a daily capacity of 20,000 to 50,000 barrels of oil or up to 250 million cubic feet of gas—are complex and expensive, costing up to $1 billion or more each. Such investments are beyond the capability of all but the largest industrial firms. The products of these plants must compete in the marketplace with all other similar products, the prices of which are often controlled by nonmarket forces. For example, the world price of oil is controlled by an international cartel, and the domestic price has been strictly regulated. These impacts on the natural market forces affecting competing fuels, coupled with uncertainties in the costs of synthetic fuel production, create a pricing risk that is, at present, unacceptable to virtually all private investors.

Possible escalation in project cost and other risks arising from environmental and regulatory delays in construction or start-up add to the uncertainties surrounding synthetic fuel product costs and prices of competing fuels, thereby further reducing the attractiveness of investment in synthetic fuel plants. Project delays resulting from environmental, regulatory, technical, or other causes could severely strain the financial resources of any firm. Indeed, an industry survey conducted in 1975 indicated that there is unlikely to be significant private investment in production of synthetic fuels from coal and shale before 1985 without some form of government incentives or substantial changes in federal regulation.

In addition to technical and economic barriers, implementation barriers also include a range of unsolved social and environmental problems. The principal social problems are community impacts of rapid growth, while the most important environmental problems relate to: (a) coal and shale extraction; (b) use of water in the conversion process; and (c) contaminating effluents from the synthetic fuel plants.

With regard to extraction, in addition to the problems cited for the extraction of coal, the major unique problems of oil shale processing include fugitive dust and the disposal of spent shale. The large quantities of spent shale resulting from commercial operations will require significant land areas for disposal, which may be affected by erosion, fugitive dust, leaching, and productivity reduction. Disposal of spent shale can cause high salinity and sediment problems. Other environmental problems may occur as a result of heavy metals and carcinogens in shale as well as land-use changes. And the mining itself could affect subsurface water flows.

In addition, synthetic fuel processes require large quantities of water and thousands of acre feet per commercial facility. In some areas the acquisition of the necessary process water will be difficult. Further, process water not used consumptively may be degraded in quality to the point it is unsuitable for other uses.

Finally, there is the potential for gaseous and liquid releases from synthetic fuel conversion facilities, which may contain polycyclic aromatic hydrocarbons. These hydrocrabon releases could include known and suspected carcinogens.

Strategic Approach

These implementation barriers, especially the economic ones, are serious impediments to private-sector development of a synthetic fuel industry in the near term.

Therefore, the strategic approach of the government would be to provide Federal financial assistance in carrying out critical technology RD&D while taking action that would mitigate against the uncertainties associated with developing an industry.

The strategy for implementing the first initiative is embodied in ERDA's coal RD&D program. This program is based on the assumption that for the private sector to eventually make widespread use of newer, lower cost synthetic fuel technologies, they must participate with ERDA in their development. Therefore, the strategy is keyed to producing concepts, processes and equipment that will meet the needs of the private sector. Specifically, the strategy aims at producing a commercially viable technology for each key stage of extracting, refining, and use, while closely involving the private sector. This strategy has led to a cost-sharing philosophy used in the demonstration projects.

But industry is involved throughout the typical development sequence which is shown in Figure III–4. The cost-sharing, for example, is concentrated in the pilot plant and demonstration plant phases but also occurs to some extent in earlier phases.

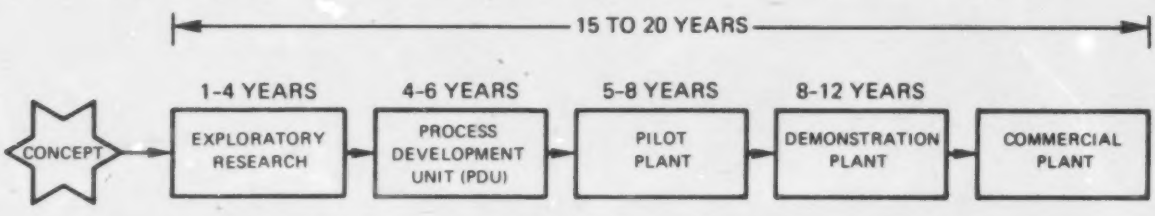


Figure III–4 Typical Process Development Sequence

The development phases take varying lengths of time depending on the complexity of the process and project, the scope of the effort, and the resources applied. (See Figure III–4.) Total development time from laboratory to completion of demonstration plant operation is typically 15 to 20 years.

The technical feasibility of the concept being developed is evaluated in each phase to determine the advisability of carrying the project to the next phase. Tentative economic and environmental evaluations start in the early stages of process development and continue through pilot plant and demonstration plant phases; more extensive evaluations are made with demonstration plants. In addition, before projects reach the stage of major construction, environmental analyses and water resource availability assessments are made; environmental impact statements are developed as required.

To have an industrial infrastructure in place to draw rapidly on these new technologies when they will be needed in the 1990s appears to require extensive commercial effort in the near term.

By and large, even if normal economic incentives were developed after 1985, it would be too late to establish the scale of industry (5 to 10 million barrels of oil equivalent per day) needed by the end of the century to hold oil imports at current levels since each plant needed would take 5 to 10 years to plan, design, site, and build. For the necessary number of plants to be operating in the mid-1990s, an industrial base on the order of 1 million barrels per day may have to exist by 1985. But uncertainties about regulations, environmental impacts, financing, labor, product pricing, and transportation must be resolved before these decisions can be made, and resolving these questions requires the construction and operation of a limited number and range of synthetic fuels plants in the next 5 to 10 years.

To determine the viability of initiating a limited number of synthetic fuels plants the Synthetic Fuels Interagency Task Force* carried out preliminary economic analysis. In that analysis, it was found that the net economic benefit of such plants depends on the ongoing strength of the OPEC cartel, the eventual price competitiveness of synthetic fuels, the influence of technology and economics of scale in reducing the cost of synthetic fuels, and the U.S. energy position in 1995. The results of that analysis showed that, on average, a slight ($1.65 billion) net **negative** benefit would accrue from the first phase of an action program to develop a synthetic fuel capacity of 350,000 barrels per day equivalent, compared with no program. Moreover, this benefit became more negative as the program grew to 1.0 and 1.7 million barrels per day equivalent, assuming a 50-50 probability that the OPEC cartel would not retain its present strength over the next 10 years. However, the analysis did not include other, nonquantifiable benefits that might accrue to the U.S. as a result of undertaking a program such as: (a) the international leverage improved bargaining position associated with positive U.S. leadership in developing alternative fuel sources; (b) the impact on industry of government support for synthetic fuels development; (c) the political as well as economic value of a decrease in world oil prices paid by importing nations; and (d) possible weakening of the cartel strength (this was assessed as negligible).

The Interagency Task Force concluded that the value of these four nonquantifiable benefits makes a limited synthetic fuels program worthwhile. Furthermore, the program to be discussed later has positive benefits greater than those calculated by the Task Force because of the elimination of synthetic crude from coal from the plant mix analyzed. This technology is the least cost efficient of all the processes examined in the analysis. Currently, the recommended first phase of the program does not include this technology until the results of current R&D efforts on coal technologies are known.

Action Program

With the clear need to move ahead in laying the foundation of a synthetic fuels industry, the Administration supported a formal market penetration program in 1975. The major objectives of this Synthetic Fuels Commercialization Program are to:

- Lay the groundwork for developing an industry infrastructure by:
  - —Investigating and acquiring information on environmental, economic, institutional, technical, and other potential problems
  - —Gathering and reviewing information on the private sector's experience in the synthetic fuels field
- Develop an energy supplement to existing and planned domestic energy production
- Improve the Nation's international leadership position in energy development by demonstrating our ability to tap our vast resources.

The program would entail two phases. In the first, or Information Program phase (350,000 barrels per day), approximately 14–19 commercial-sized demonstration plants would be constructed, including facilities for high-Btu coal gasification, oil shale conversion, substitute utility of industrial fuels, and conversion of waste material to liquids and gas. This first phase of the program would demonstrate and obtain information on the technical, economic, and environmental feasibility of synthetic fuel plants, using different available energy resources and technologies.

* Published in November 1975.

Table III–8. Illustrative Plant Mix

Type Plant	Probable Number	Est. Production Capacity—Each Plant	Affecting Industry
High-Btu Coal Gasification	3	40,000 BPDE	Pipeline Gas
Oil Shale Conversion	2–4	10,000 to 50,000 BPDE	Petroleum
Substitute Fuels Utility/Industrial	6–7	5,000 to 25,000 BPDE	Utilities/Industrial Users
Biomass Conversion (Gas/Liquid)	3–5	1,200 to 6,000 BPDE	Various
Totals	14–19	350,000	

To illustrate, one **possible** plant technology/resources is shown in Table III–8.*

In carrying out the first phase of the synthetic fuels program, the Federal Government would reduce financial uncertainties by providing limited economic incentives to the private sector to construct and operate the commercial demonstration plants. The Government would also provide limited guarantees or, if necessary, assistance to localities for needed socio-economic infrastructure planning and development. Finally, the Government would help expedite the construction of the plants by facilitating the necessary federal regulatory permits and clearances.

The program might be expanded to 1 million barrels of oil equivalent per day during the second phase, if the energy situation warranted and if the environmental, social, technological, and production cost problems were sufficiently tractable. However, this decision is not anticipated until 1978–1979 and would depend on overall energy RD&D results, industry response to the program's first phase, and the results of information on environmental and other impacts.

In addition to laying the groundwork for a viable synthetic fuels industry, important RD&D will be carried out on advanced synthetic fuel technologies. These efforts would support development of a number of synthetic fuel processes in parallel, moving from basic R&D in the laboratory, through process development units (PDUs) and pilot and demonstration plants, to market penetration. A significant number of liquefaction and gasification PDUs and pilot plants are currently operating; additional PDUs and pilot plants are being designed or are under construction. Finally, a contract for a clean boiler fuel demonstration plants (COALCON) has been let, and the plant is being designed. Additional contracts—for high-Btu and low-Btu demonstration plants—will be initiated shortly.

In parallel with these legislative, budgetary, and administrative actions, ERDA is carrying out a program, still being formulated, will include a number of efforts, such as measurement of water quality at test sites and the prediction of degradation resulting from commercial operations; investigation of options that minimize the need for water; development of improved recycling and effluent treatment techniques; and evaluation of process and by-product pollutants and associated health effects. In addition, assessments of the potential health impacts would require environmental and health information which involve both short-term and long-term studies. Data from these studies are necessary for setting appropriate regulagram to address environmental concerns. This protory standards and for the design of effective control technologies, including incineration, collection-disposal, and chemical absorption techniques.

Investigations into revegetation dynamics and plant species selection are continuing. *In situ* processing of both coal and oil shale is being given considerable attention. However, the *in situ* approach would leave most of the solid waste products in place. In addition, there could still be problems of land subsidence, hydrocarbon and particulate emissions through the fractures, and contamination of aquifers. Studies of oil shale formation and kerogen content and the characteristics of pollutants, seam size, and associated underground aquifers are being conducted.

Efforts also are under way to establish air pollution control requirements to prevent or minimize environmental pollution from production and use of synthetic fuels. Initial efforts in the program are concentrated on assessing the potential environmental effects of the coal-conversion processes. Control technology aimed at controlling sulfur and particulate emissions from hot, acidic gas streams is also under development.

Specific Steps in Action Program

Moving ahead with the first phase of the market penetration program requires a series of legislative, budgetary, and administrative actions, including:

- Legislative authorization of the limited financial incentives to be awarded to the private sector for

* The actual plant number and sizes may vary from this estimate, depending on the proposals received from interested firms and final environmental impact statements.

Table III–9 Geothermal Resources—Estimated Recoverable Heat with Present or Near-Term Technology without Regard to Cost†; (In Quads)*

RESOURCE TYPE	KNOWN	INFERRED	STATE OF TECHNOLOGY
HYDROTHERMAL CONVECTIVE**			
VAPOR DOMINATED (>150°C)	2	2	COMMERCIAL
LIQUID DOMINATED			
HIGH TEMPERATURE (>150°C)	20	110	TEST PHASE
LOW TEMPERATURE (90°-150°C)	80	250	TEST PHASE
GEOPRESSURED			
ELECTRICAL UTILIZATION	100	230	EXPERIMENTAL
METHANE PRODUCTION	500	1500	
HOT DRY ROCK	80	240	EXPERIMENTAL
MAGMA ++	80	240	UNEXPLORED
TOTAL	~900	~2500	
GRAND TOTAL (KNOWN PLUS INFERRED)	3400 QUADS		

* NORMAL GRADIENTS ARE NOT INCLUDED AT THIS TIME AS THEY ARE NOT PRESENTLY CONSIDERED RECOVERABLE. 1 QUAD=10^{15} Btu's.
** DOES NOT INCLUDE LESS THAN 90°C SYSTEMS, ALTHOUGH SUCH SYSTEMS MAY BE ECONOMICALLY EXPLOITABLE ESPECIALLY FOR NON-ELECTRIC APPLICATIONS.
† ASSUMING 2% EXTRACTION RECOVERY, 8% CONVERSION EFFICIENCY.
++ MAGMA RESOURCES MAY BE RENEWED BY NATURAL RESUPPLY FROM THE INTERIOR OF THE EARTH; THEREFORE, THIS ESTIMATE MAY BE CONSERVATIVE.

SOURCE: DEFINITION REPORT: GEOTHERMAL ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM (ERDA-86), OCTOBER 1975.

demonstration plants. Although loan guarantees are essential, price guarantees and grant authority may also be needed to ensure all major synthetic fuel technologies and the important types of resources are included in the program. If needed, price guarantees and grant authority would be sought under the authority of the Nonnuclear Act.

- Legislative authorization of the limited financial guarantees to localities for needed socioeconomic infrastructure as well as assistance for planning and development. This could be in the form of guarantees of local government debts incurred to provide the necessary infrastructure.
- Continue the necessary environmental studies that will ensure environmental acceptability of a commerical synthetic fuels industry.
- Evaluate mechanisms to expedite federal regulatory permits and clearances.
- Administrative action to ensure the technology demonstrated by the program will be available to all interested firms at a reasonable cost.

Geothermal

The Nation's geothermal resource base is one of the largest potential domestic energy sources. As estimated by the U.S.G.S., ERDA-86,* reported the total heat content of the accessible geothermal resource base (depth less than 10 km) to be about 600,000 quads, excluding the highly diffuse "Normal gradient" resource. However, only a small fraction of this base is recoverable in usable form with presently foreseeable technology. On the basis of conservative assumptions of extraction and conversion efficiencies the total recoverable energy from this base, with near-term technology but without regard to cost, was estimated to be only about 3400 quads, which is still about 45 times the total U.S. energy consumption in 1974,** as shown in Table III-9. However, as esti-

* Definition Report Geothermal Energy Research, Development and Demonstration Program, ERDA–86.
** However, a significant proportion of these resources exist away from population centers and thus may not be fully exploitable.

mated in ERDA-48, only a small fraction of this resource (reaching an annual level of approximately 5 quads by the end of the century) is estimated to be extractable over the next 25 years. Economic exploitation of this resource will require the reduction of technological and financial risks, the reduction or removal of a number of institutional barriers, and the development of technology to provide acceptable control of possible environmental problems. The latter, often site- or type-specific, include subsistence, brine disposal, and the emission of noxious or toxic substances, such as hydrogen sulfide, in varying amounts.

Only the vapor-dominated hydrothermal resource (The Geysers in California) has been economically exploited in the U.S. This type of resource is rare and amounts to only a few percent of the known or inferred total geothermal resources. The more extensive liquid-dominated hydrothermal resources have not been exploited to any degree for power production in the U.S. (although there has been some foreign experience, using techniques currently not environmentally acceptable in this country). A few hydrothermal development efforts in the U.S. are in the technology verification or pre-pilot stage, but the technology for tapping the larger geopressured resources along the Gulf Coast is in the stage of engineering feasibility studies. Commercialization of geopressured resources will probably follow that of hydrothermal. Thus, the liquid-dominated hydrothermal resources represent the principal near-term opportunity for exploitation. It awaits the development of improved versions of existing reservoir assessment, extraction, and utilization technologies, and the solution or abatement of a number of environmental and institutional problems, as discussed below.

Implementation Barriers

Because the costs of extracting energy and of controlling environmental impacts vary greatly among the different types of hydrothermal reservoirs, mature technology will be directed initially at the development of the **most favorable**, known hydrothermal reservoirs. For some sites, based on an extension of foreign technology, the cost of electric power generated by geothermal resources has been estimated at well below the cost of power produced in conventional coal or nuclear plants. However, uncertainties about the actual power production costs and reservoir lifetime associated with an untried geothermal site, as well as the basic uncertainties of a new technology, have discouraged most utilities from proceeding with geothermal energy development. And the few utilities that have taken an interest have had little success in attracting support from public utility commissions, lenders, or investors.

The reasons impeding the commercial development are principally threefold:

1. **Lack of reliable, detailed resource information**, e.g., on the changes in the characteristics of a reservoir resulting from energy extraction
2. **Lack of proven domestic technology** for use with all but one type of recoverable resource, the vapor-dominated hydrothermal
3. **Legal and regulatory complexities** involving leasing, resource ownership, water rights, taxes, and the like.

In addition, insufficient knowledge of possible environmental impacts and the lack of proven control techniques for all but the vapor-dominated hydrothermal resources inhibit rapid commercial development. The environmental issues fall into three areas.

First geothermal development may produce seismic disturbances and subsidence. Removal or injection of massive quantities of water may result in seismic activity, with effects varying from site to site. Withdrawal of water may also cause subsidence as reservoir pressure is decreased, unless appropriate control measures are taken, such as brine reinjection.

Data required to predict subsidence rate and seismic activity are currently unavailable. Potential seismic activity at each site must be assessed and the potential effects of withdrawal or injection of large quantities of water analyzed and monitored. Ground levels must be monitored and base lines established with predictive modeling prior to development. Reinjection technologies must be explored as important environmental control measures.

Secondly, quantities of air pollutants released from hydrothermal activities are not known. Hydrogen sulfide, emitted in large quantities is a significant pollutant because of its toxicity and disagreeable odor. Methods of treating large gas volumes with low H_2S concentration must be developed.

Third, where a fresh water aquifer occurs above a geothermal reservoir the fresh water could be contaminated by tapping the geothermal strata. Saline waste waters cannot be discharged into surface waters without treatment. Subsurface reinjection of brine-liquid effluents may represent a significant control measure not only for brine disposal but also for subsidence, although it may be accompanied by other environmental problems such as seismic disturbances (see above).

When such reinjection is not feasible or desirable, surface treatment and disposal must be considered. Because it may also introduce trace contaminants, removal of toxicants must be effected and environmental impacts of effluents on fauna and flora must be determined. Unless adequate controls are devised and implemented, the associated water

pollution problems may inhibit development of geothermal energy.

ERDA-86 has estimated that, without Federal involvement, only about 1,500 MW of geothermal power would be on line by 1985. Most of this would result from the planned expansion of vapor-dominated geyser fields with limited additions of liquid-dominated hydrothermal resources in southern California and scattered small-scale, nonelectric applications in the western U.S.

Strategic Approach

Although the necessary detailed analyses of the various types of geothermal resources have not been completed, it appears that the development of geothermal energy may have an attractive positive rate of return. However, as perceived by private investors, who make conservative estimates of technical and other risks, this rate of return seems marginal. Government-sponsored studies of the more economically attractive hydrothermal resources suggest that these could, where available, provide electricity at competitive prices. Equally important, capital costs of installed hydrothermal capacity are expected to be competitive. As in any unproven technological area, significant uncertainties exist in the economic analyses and sufficient analysis has not been done to derive predictions of expected rates of return that will be accepted by utility decisionmakers and private investors.

Nonetheless, it is ERDA's current judgment that the geothermal resource will prove to be a commercially attractive source of energy. However, the private sector has not utilized the geothermal resource beyond the limited dry steam type because of existing barriers. Both utilities and resource companies will have to cooperate in individual projects.

To address this impasse, a limited and targeted governmental program could help a fledgling industry over the initial barriers and permit the Nation, as a whole, to realize geothermal's full potential. The strategic approach governing commercialization efforts would encompass four principal elements.

First, the Government would assist the private sector in identifying and verifying the extent and lifetime of usable geothermal resources. This assistance, consisting of the U.S. Geological Survey's regional and national assessment of geothermal resources, the development and testing of improved exploration techniques, and an accelerated leasing program to improve the availability of Federal land, would lessen the uncertainties and risks now confronting investors.

Second, Government would assist industry in utilizing the sizable hydrothermal resources. Greater utilization of hydrothermal resources will enable industry to gain the momentum necessary to undertake the development of the other forms of geothermal resources, such as the still larger geopressured and hot dry rock types. (The "momentum" approach is based on the current judgment that breakthroughs in an already generally understood technology are not probable; rather, as additional experience is acquired, sustained and systematic performance and cost improvements in extraction and utilization will accrue.) However, to tap these resources, the necessary technology, which is improving and is closely related to that already in operation with vapor-dominated resources, must be brought to fruition. Parallel to efforts to accelerate market penetration, Government RD&D would assist in bringing the technology for the advanced geopressured and hot dry rock sources to comparable maturity.

Third, the Federal Government can act as a catalyst, or "broker" in forming a consortia of institutions needed to commercial geothermal resources—i.e., electric utilities, resource development companies, specialized equipment manufacturers, and local government.

Although electric utilities are not suited to conducting the exploration, drilling, and production operations because of regulatory constraints, they are necessary consortia participants because they form the largest single market that can be immediately identified. Other possible user industries, such as those requiring process heat or those that could use geothermal heat for space heating and cooling, are more diffused and less readily identifiable, but form an important future market for geothermal energy and should be included.

The oil and gas industry is the most prominent candidate among the resource developers because it has basic commitment to energy supply, expertise in the technologies of resource discovery and extraction, the equipment (or ready access to the equipment) necessary for discovery and extraction, and access to the capital required to support the effort. Other possible resource developers, whose problems also will be considered, include the minerals industry and the specialized exploration industry beginning to form around geothermal energy.

Unlike most other energy resources, geothermal energy is nontransportable. This aspect alters this traditional perspective of the market. The developer no longer has a large commodity-like market for his resource; rather, he must sell it to those specific users able to exploit the specific characteristics of the resources and willing to locate at the specific site of the resource. The user no longer has a large market from which to draw his energy; rather, he must accept the specific resource and its finite limitations and deal with a single developer. He also must accept the specific site, thereby losing

all flexibility in location; availability of services such as transportation, transmission line location, and the public services; and proximity to markets. (This situation is comparable to that for hydroelectric power.) The community, in permitting the development of the resource, must accept the impacts not only of the extraction of the resource, which can be relatively easily foreseen, but also of its use, which are not so easily foreseen and can be major. Thus, three parties—the developer, the user, and the community—must have individual perceptions of profitability before development can proceed.

The Federal Government would play this broker role in two ways. A planning and program updating effort would acquire information and develop potential geothermal utilization growth scenarios for high-payoff regions. The regional cost/benefit and socioeconomic analyses performed as input to this planning would spur action in the specific cases and help determine whether Federal assistance would be beneficial. In addition, and growing out of the planning, Federal assistance may be provided for high-leverage cases in one or more of four forms: (a) direct contracts with industry; (b) cost-sharing of RD&D or demonstration projects with industry; (c) loan guarantees to obtain necessary capital; and (d) accelerated leasing of public lands.

The fourth element of the Government's strategic approach is "seeding." Specifically, the Government may provide the above forms of assistance to develop the prototype plant (i.e., the first of many) in resource-rich fields. Given the nature of geothermal technology that makes numerous moderate-sized plants (e.g., 50 MWe) more appropriate than a few large plants, the experience gained from developing a prototype may be transferred quickly and economically to construction of the remaining plants in the field. In this way, limited Government assistance could help industry acquire first-hand experience and facilitate the development of the industrial-banking-user infrastructure.

Action Program

The action program necessary to effect this strategic approach will consist of five steps:

- DOI will evaluate Federal lands for geothermal leasing, issue leases, and administer and supervise leases. The role of the Bureau of Land Management is to encourage the utilization of geothermal reservoirs by designing and implementing an economically attractive leasing program.
- ERDA will carry out programs to establish the technical, economic, and environmental acceptability of geothermal technologies.
- Regional analysis will be undertaken to determine the match between geothermal resources and needs within the region.
- The geothermal loan guaranty program is being developed to facilitate the availability of risk capital to the geothermal industry; alternative economic incentives will be analyzed and recommended when in the national interest.
- Studies to determine the environmental and socioeconomic implications of the application of geothermal technologies will be carried out, and appropriate control technologies, standards, regulatory policies and planning methodologies will be developed.

Solar Heating and Cooling in Buildings

Solar energy is a very large, nondepletable, domestically available resources for the United States and is now virtually untapped. Among the numerous possible technologies for applying solar energy for U.S. energy requirements, direct heating and cooling of buildings offers the best opportunity for early large-scale application and commercialization. A substantial market potential is present because about one-fourth of the total national need is for building operational requirements and 80 percent of that usage is for space temperature control and heating water. Since most of these requirements are now dependent on the use of depletable fossil fuels, either directly or through generation of electricity, widespread use of solar energy to heat and cool buildings can substantially reduce such dependence. Specifically, the installation of solar heating and cooling systems in about 1 percent of the present buildings in the United States would save the equivalent of about 80,000 barrels of oil per day. If 10 percent of the then-existing buildings were solar equipped by the year 2000, oil-equivalent savings of about 1 million barrels of oil per day—or about 2 quads—may be realized.

The basic technology for using solar energy at low temperatures is reasonably well understood. Significant numbers of different types of systems for space heating and water heating are being rapidly developed, tested, and installed. For example, more than 300 solar-heated buildings are completed or under construction in the U.S. The total production of solar collectors in 1975 was in excess of 700,000 square feet. The cost of the installed systems in 1975 is estimated at about $10 million.

Results of economic analysis indicate that, for fuel costs in the $10-per-million-Btu range (equivalent to about 3 cents per KWh—which is near the average electricity cost in the U.S.), solar heating system costs must be below about $15 per square foot of installed collector.

Although little long-term performance data exist and only general interim standards have been implemented, recent studies indicate that some systems are beginning to be marketed at costs well under

$15 per square foot of installed collector area (based upon prices being quoted by at least one manufacturer). However, other recently completed buildings show system costs ranging from $10 to $20 or more per square foot of installed collector and costs of some experimental, high performance heating and cooling systems appear to be on the order of $20 to $50 per square foot of installed collector area. Significant questions, of course, remain concerning the reliability, operating effectiveness and maintenance of these systems over their projected lifetimes.

Present systems, then, are commercially competitive in only a limited range of applications and geographic regions. If the use of such systems is to grow, it will be necessary for the private sector and, in some instances, the Federal government, to continue new-technology research, but also to refine the present technology and to demonstrate its practicality.

While solar heating and cooling is considered an environmentally beneficial technology, a systematic assessment has not yet been completed of direct and indirect environmental issues of the solar product life cycle. The production of economic components for solar heating and cooling systems may be preceded by the development of new materials and equipment. Emissions and materials use related to fossil fuel consumption must be balanced against increased (and new) environmental impacts and materials requirements from the solar industry.

Implementation Barriers

The principal barrier to successful commercialization of solar systems is their lack of economic competitiveness with available conventional systems and fuels. Except in special cases, present solar heating and cooling systems must be used in conjunction with normal-sized conventional systems to ensure that continuous hot water and space conditioning are provided during extended periods of reduced sunshine. Thus, over the near term, solar systems will generally require substantially larger investments than conventional systems. The extent of such additional investment and the speed and method of payback (by operational fuel savings and in potential property value enhancement) are crucial to successful market development. Competitive use of solar systems is contingent upon many factors, including the unit cost for purchase and installation of available solar equipment, the climate and average available sun flux, the initial and operational cost of conventional heating and cooling systems, the cost of the additional conventional energy, and the availability of capital funds.

If solar heating and cooling technology should become economically advantageous (through either cost-effective improvements in solar technology or cost increases in alternative energies), it will be constrained by other barriers including two that are inherent in any technology innovation in the construction industry. First, home or building buyers show a marked preference for lower initial costs. Therefore, because solar heating and cooling systems typically require higher initial expenditures, the average homeowner must be convinced the system provides sufficiently rapid operational returns or enhancement of property values to justify the additional investment. Second, there generally is a strong reluctance by speculative builders, developers, lending institutions, and other major components of the construction industry to accept the risk of introducing a new technology to an already high risk industry. The problem is intensified by the current absence of consensus standards on construction and performance, modifications in current construction practices, and lack of information on systems reliability and maintenance requirements.

Other institutional, social and legal barriers that must be overcome include the definition of appropriate land use regulations, air and sun rights, and building codes, as well as acceptance of the unfamiliar solar technology by mortgage lenders and insurance groups.

Strategic Approach

The overall goal of the Federal program for solar heating and cooling is to stimulate the advancement of an industry to produce, distribute and service solar hardware for hot water heating and space heating and cooling for residential and commercial buildings. The Government will conduct its programs to encourage the participation of industry organizations, consumer groups, and state and local government. The program is structured to demonstrate the practical use of solar heating technology by the end of 1977, and to demonstrate the practical use of combined heating and cooling technology by the end of 1979. This will be accomplished by a series of cyclical demonstration projects applicable to new and existing buildings, and by research and development to advance solar technology. The first two cycles of demonstration projects will concentrate on space heating and hot water supply for both residential and nonresidential buildings, and subsequent cycles will emphasize combined space heating and cooling and hot water supply. The RD&D program is designed to yield components having lower cost, greater durability and improved performance, as well as a significant advance in the ability to predict the performance of solar systems. Improved systems should be able to reduce, and perhaps eliminate the need for conventional backup systems. If program objectives are met, the market

could be increased to 10 percent of the new building starts in 1985.

Action Program

The major elements of the Federal program include:

- Residential Demonstrations
- Commercial Demonstrations
- Development in Support of the Demonstrations
- Research and Advanced Systems Development
- Collection and Dissemination of Information
- Additional Policy Measures Required to Achieve Rapid and Widespread Utilization.

Chief among the program elements is the demonstration of working systems to be carried out in close conjunction with private industry. Solar heating and cooling systems are planned to be installed and operated in several cycles through 1979 in a number of commercial buildings and residential family units to test specific systems in specific building types and under various climatic conditions in the U.S. Both new construction and retrofit systems are planned to be demonstrated, including many types of passive systems.

A heavy emphasis will be placed upon the involvement of small business in the demonstration of solar heating and cooling and in research and development to produce improved systems. Involvement of small business is well above 50 percent in most areas of the Federal program. The unique capabilities of small business organizations are recognized in their high innovation rate, lower organizational inertia, and flexibility in meeting local and regional needs.

This multicycle demonstration program, in which HUD will manage the residential applications while ERDA manages the demonstrations on commercial buildings and provide the necessary experience with viable applications. This, in turn, will provide information necessary to improve solar heating and cooling systems for use under a variety of conditions. The later phases will demonstrate cooling as well as heating systems. Efforts are intended to produce a substantial reduction in the installed heating cost. The demonstration program will also provide information on system reability and maintenance, and help to establish needed construction and operating standards. An additional requirement for early commercialization is the need for consensus standards. ERDA is working with professional and trade organizations, such as ASHRAE* and ANSI** to develop such standards. The demonstrations will also provide substantive experience for identifying and resolving legal and regulatory problems, and will exhibit the nature of applied solar technology to potential users and lenders. Also, they will provide an opportunity to identify and resolve operational and jurisdictional problems within the construction industry.

A comprehensive socioenvironmental assessment for the national solar energy program, including heating and cooling, is under preparation and is due in September 1976. This study will help verify benefits and identify any possible deleterious impacts of solar space heating.

In parallel with the commercial and residential demonstration programs, a Federal Buildings Program is being developed by FEA and ERDA. The basic aim is to encourage all Federal agencies to use solar heating (and potentially solar cooling) in their buildings if a life-cycle cost analysis indicates economic viability. ERDA is working with FEA to implement the project, wherein ERDA can provide additional experience by solar heating and cooling demonstrations on Federal buildings and increase the early market for solar equipment. This, in turn, should accelerate industrial interest in producing solar equipment and stimulate solar applications in the commercial and consumer sectors of the economy.

Breeder Reactor

The capability of the Nation to draw on nuclear energy to meet the electric and other energy requirements of this country beyond this century will depend on having available a proven, environmentally safe commercial breeder system by the 1990's that can effectively use total uranium resources—i.e. U-238 as well as U-235.

The Liquid Metal Fast Breeder Reactor (LMFBR) concept, a technology that has been demonstrated to be technically feasible, is the chief candidate for meeting this need. Eight breeder reactors are in operation around the world. However, the LMFBR is not now a commercially viable option that utilities can purchase to satisfy their electrical energy generation requirements. Specifically, several technological areas must be investigated and the total system concept must be demonstrated to be economically competitive and socially acceptable to the Nation.

Market Barriers

The specific technical, economic, and psychological barriers to currently marketing a breeder reactor are:

- An insufficient engineering base, which prohibits the nuclear manufacturing industry from designing and constructing safe, reliable LMFBR power plants and fuel cycle facilities in commercial sizes at competitive costs.

* ASHRAE—American Society of Heating, Refrigeration and Air Conditioning Engineers.
** ANSI—American National Standards Institute.

- The lack of advanced fuel and core materials and the technical basis for producing reliable and economic fuel systems, which prohibits LMFBR power plants from generating new fissionable material at a rate commensurate with the national growth in electric power demand.
- Lack of utility operating experience to demonstrate that LMFBR systems will perform safely, economically, and reliably in a power generation network.
- Lack of public acceptance in LMFBR power plants and fuel cycle facilities for safety, economic, and environmental reasons.
- Unknown capital costs which make the breeder system economically noncompetitive with other commercial power generation systems.

The development of a responsive overall program was addressed in the **Final Environmental Statement—Liquid Metal Fast Breeder Reactor Program.*** In his review of this document, the Administrator of ERDA stated:

"The FES shows that the major areas of uncertainty lie in plant operation, fuel cycle performance, reactor safety, safeguards, health effects, waste management, and uranium resource availability. I find that the availability of sufficient information to resolve these areas of uncertainty is crucial before ERDA can render a meaningful decision on the commercialization of that technology, i.e., the environmental acceptability, technical feasibility and economic competitiveness of LMFBR technology for widespread commercial deployment. ERDA has programs in place in each of these areas. The LMFBR Program has focused on plant operation through the development of experience in LMFBR demonstration plants, on fuel cycle performance through its base programs of fuel cycle development, and on reactor safety which is an integral part of both the plant demonstration program and the base program. The other areas of uncertainty—safeguards, health effects, waste management and uranium resource availability—are not unique to the LMFBR, and are being addressed generically by other programs."

To achieve this, eight specific areas of investigation are now under way:

1. **Components.** Developing engineering component options with demonstrated capability for meeting the safety, reliability and performance requirements of large LMFBRs operating on utility systems, with demonstrated capability of being reproducible, economical, and manufactured within cost and schedule.
2. **Materials.** Developing structural materials and design methods permitting economic design and operation of components at acceptable levels of plant availability and at up to 40-year lifetime for inaccessible components.
3. **Physics.** Developing design data and confirm computational methods with an accuracy sufficient to enable specification of core loadings, shielding requirements and control requirement for large LMFBRs factors of conservatism consistent with low design cost, low plant costs, improved plant performance and competitive power costs.
4. **Chemistry.** Developing instrumentation and methods for monitoring and controlling corrosion processes and system impurities to levels that preclude degradation of component and system performance over the plant life, and develop processes for removing sodium and radioactive contamination from components being repaired without affecting service life.
5. **Safety.** Developing and confirming analytical methods that will permit design flexibility relative to current practice, allow greater design confidence, improve efficiency and reduce costs and schedules, and to demonstrate the inherent safety of LMFBRs prior to a large-scale utility commitment to LMFBRs in the 1990's.
6. **Plant Experience-FFTF, CRBRP and PLBR.** Designing, constructing, licensing, operating, and maintaining LMFBR power plants on an electric utility power generation network, thereby demonstrating the economic, safety and environmental advantages of the LMFBR concept and establishing the industry capability to offer a salable plant in a competitive market.
7. **Fuels.** Developing fuels system options with performance characteristics that will ensure the commercial viability of early LMFBR power plants and that will enable achievement of doubling times of 10 to 15 years as determined by energy growth after 1990.
8. **Fuel Recycle.** Developing and demonstrating fuel reprocessing systems that accommodate all fuel system options and allow for the rapid fuel recovery and turnaround times necessary to ensure doubling times of 10 to 15 years.

However, to ensure the plants are accident-proof and environmentally acceptable, expensive design add-ons may be necessary. Therefore, several important issues are under investigation which, when satisfactorily resolved, will permit freedom to produce more economical plant designs.

In his findings on the **Final Environmental Statement,** the Administrator stated further:

"On the basis of the material set forth in the FES, I find that if the reference plan and its supporting programmatic efforts are vigorously pursued, sufficient information would be available as early as

* ERDA–1535 of December 1975.

1986 to resolve the major uncertainties affecting widespread LMFBR technology deployment and therefore to permit an ERDA decision on commercialization of that technology."

Action Program

As positive results are obtained from these investigations, a series of reactor plants will be designed, built, and operated to confirm the results and provide experience on a total reactor plant system. The Experimental Breeder Reactor-II has been operating since 1963 and the Fast Flux Test Facility is under construction, with operation due to begin in 1979.

In design is the Clinch River Breeder Reactor Plant, (with a start-up date of 1983), a cooperative venture with industry and the utilities. Target plant designs that will serve as a basis for further cooperative projects are being developed. This will lead to a Prototype Large Breeder Reactor that will provide experience with a commercial-size LMFBR.

These programs and supporting efforts are aimed at permitting a decision by 1986 as to whether commercial deployment of the technology is acceptable.

Fusion

Drawing on plentiful deuterium and tritium found in the oceans as fuels resources, fusion technology, if practically developed, could provide essentially limitless amounts of energy. Accordingly, the technology was designated as one of the three high-priority longer term energy supply technologies.

With this technology, energy is produced when nuclei of light atoms are joined or fused into larger nuclei, with an attendant release of energy. For such to occur, light elemental nuclei in the form of a plasma must be confined at high densities and temperatures for adequate periods of time.

The development and demonstration of this is being pursued along two different lines. The first is an investigation of several magnetic confinement systems; the second is research into inertial confinement by means of energy lasers or electron beams.

Magnetic Confinement Fusion

The primary emphasis in the magnetic confinement program at this time is the development of a sufficient understanding of plasma behavior and magnetic confinement systems to attain simultaneously the required plasma densities, temperatures, and confinement times. Engineering activities parallel to and coordinated with the scientific studies of plasma production, containment, and heating provide the technological base for near-term experimentation and, ultimately, for development of fusion power reactors.

The Magnetic Confinement Program is organized into four subprograms that emphasize the different aspects of the program's major goals. The Confinement Systems Subprogram conducts the major experiments to achieve the necessary conditions for practical fusion power. The Development and Technology Subprogram provides the engineering support and technology base for the major magnetic confinement experiments, and conducts fusion test facility and engineering experiments and studies related to reactor design. All theoretical and computational activities in support of the Magnetic Confinement Program as well as small-scale experimental studies are carried out in the Applied Plasma Physics Subprogram. The Reactor Projects Subprogram is responsible for the construction phase of the Tokomac Fusion Test Reactor and other large projects.

The most promising magnetic confinement concept at this time is the Tokamak. The Tokamak Fusion Test Reactor, on which construction began in FY 1976, is expected to be the first experiment to produce sizable quantities of fusion energy. In addition, backup approaches to the Tokamak are being pursued. The principal alternatives are the theta pinch and magnetic mirror concepts, which involve alternative magnetic configurations.

The magnetic confinement approach has recently achieved ignition-level temperatures and a ten fold increase in plasma confinement conditions in a magnetic mirror device. A similar advance has been achieved in a Tokamak device with confinement conditions five times better than any previously reported and only a factor of ten below the value needed for fusion break even. During FY 1977, the program will use the knowledge gained by these accomplishments to accelerate attainment of net fusion power and improve the performance requirements of the next generation of machines.

The major, planned milestones of this program are: (1) the production and understanding of ignition-level hydrogen plasmas in 1978-1980; (2) the production of substantial quantities of thermal energy in the Tokamak Fusion Test Reactor by 1982; (3) the production of substantial quantities of electrical energy in Experimental Power Reactors in the late 1980's; and (4) the operation of a commercial-scale Demonstration Power Reactor by the late 1990's.

Inertial Confinement Fusion

The Inertial Confinement Program seeks to determine the scientific feasibility of laser- and electron-beam-initiated thermonuclear burn, using principles of inertial confinement and applying it to such areas as nuclear weapons effects simulation, nuclear weapons physics modeling, military power systems, and commercial power production.

Program strategy involves the maintenance of a research, development, and application core research program within the ERDA laboratories. At the same time, full use will be made of unique university and industrial capabilities in support of the core program. Broadly based efforts in universities and industry will complement and extend the national laser fusion program base.

Studies of laser-matter interaction phenomena and advances in laser technology permitted the achievement of the first major program milestone of pellet compression in FY 1974. As more powerful laser systems become available, the next major milestone of significant fusion yield is expected to be achieved in FY 1978-1979, followed by scientific break even in FY 1981-1982 and net energy gain by the mid-1980's. Based on the success in achieving these milestones, an operational test system could be operational by the late 1980's and a demonstration commercial power plant, by the mid-1990's.

Solar Electric

As indicated earlier, solar energy is a very large, nondepletable, domestically available resource. If a small percent of the incident energy could be economically harnessed, a significant fraction of projected U.S. energy needs could begin to be met by the year 2000.

To tap this energy, four technologies appear most promising:

—**Solar thermal electric** generation involves the concentration of solar energy to create the high temperatures needed to heat water or other fluids to power turbines which, in turn, drive electrical generators. Total energy systems, based on solar thermal electric system concepts, can also supply industrial process heat or space heating and cooling needs.

—**Solar photovoltaic** conversion involves the direct conversion of sunlight to electricity through use of arrays of photovoltaic cells.

—**Wind energy** conversion systems commonly convert wind to mechanical energy, which may be used directly to drive energy storage devices (e.g., pumped hydrostorage, flywheels, or compressed gases) or electric generators.

—**Ocean thermal** energy conversion uses the temperature differential occurring between the solar-heated ocean surface and the deeper, colder water as a heat source to drive a working fluid in a thermodynamic cycle that powers turbines to produce electricity. Other renewable ocean resource options such as tides, waves, salinity gradients, and currents are also being explored.

Market Barriers

Although solar energy can be tapped with these technologies, by and large, it cannot now be tapped economically. For example, for photovoltaic electricity to be competitive with alternative sources (e.g., coal), the cost per watt of solar collector arrays must be reduced by a factor of 50 to 100. Similarly, wind energy can now only be used for some limited applications (e.g., in remote areas or in a fuel saver mode), but the regional and intermittent nature of the source and the absence of economic methods of energy storage make it uneconomical for meeting general energy needs.

Strategic Approach

Given these market barriers, the general thrust of the RD&D program is to develop the technology, and systems and gain the experience that will result in substantial reductions in the cost of using solar energy. However, since the specific problems with each of the four technologies are distinct, their respective RD&D program strategies are different.

In wind energy conversion, the program strategy is to stimulate industrial efforts to design more efficient rotor systems and to lower capital costs through prefabrication and more efficient production techniques, and through demonstrations of reliable, economically viable wind energy systems.

The program strategy for solar photovoltaic conversion is to lower the cost per watt of collector arrays by a factor of 50 to 100 from present levels by: (1) producing low-cost photovoltaic materials through large-area crystal growth, high-volume sheet production, modified array encapsulation, and improved cell and array designs; and (2) encouraging industry to achieve volume production so that they may gain manufacturing experience and develop economies of scale.

In solar thermal electric, the program strategy is to focus on small-scale models, large-scale experiments, and pilot plants to improve performance-to-cost ratios, reduce technical and economic risks, and verify operating characteristics. The critical areas of cost will be identified as a basis for subsequent programs that will concentrate on those alternatives with the greatest promise of lower costs.

Ocean thermal gradient conversion, while theoretically economical, has not yet been demonstrated as a practical energy source. Using current technologies to scale to large sizes requires major component development. For example, the improved, heat exchanger technology needed to use the small temperature differentials and to overcome the potential problems associated with biofouling has not yet been developed and is critical to the overall potential

of the technology. Once such technologies have been demonstrated, it will be possible to develop large-scale components, subsystems, and full-scale ocean thermal systems.

Action Program

An action program has been designed for each technology area to carry out the approaches described above.

- **Solar thermal conversion.** Completion of a 5-megawatt solar thermal test facility in FY 1978 will permit testing and evaluation of the major subsystem concepts under development for central receiver approach to solar thermal electrical conversion. In addition, the conceptual design of a 10-megawatt electric solar thermal pilot plant is scheduled for completion in FY 1977, with construction of the pilot plant scheduled for initiation in FY 1978. Finally, initial operation of the total energy test bed is scheduled for completion in FY 1977.
- **Solar photovoltaic conversion.** Attractive applications that will advance the widespread use of solar photovoltaic conversion systems will be identified by the end of FY 1977. In addition, a major series of experiments on multikilowatt photovoltaic energy conversion systems will be initiated in FY 1976; these experiments will provide valuable operational experience and will stimulate the development of the industrial base. Thirdly, RD&D on materials and fabrication techniques will be carried out with a goal of achieving a price of less than $2,000 per peak kilowatt for concentrated photovoltaic systems by FY 1979 and for planar solar cell arrays by 1982.
- **Wind energy conversion.** It is anticipated that, in cooperation with utilities, the design, fabrication, and installation (at two climatically different sites) of two multi-hundred kilowatt wind energy systems will be completed in FY 1977, with the cooperation of utilities. In addition, completion of the design and fabrication of a megawatt-scale wind energy system is scheduled for FY 1977. This system will be of a cost-optimum design for high-wind-velocity sites. During FY 1977 the initiation of field testing of several innovative and advanced wind energy conversion concepts, and of a number of wind energy conversion systems suitable for small-scale applications will be undertaken.
- **Ocean thermal energy conversion.** During FY 1977, studies of programmatic planning alternatives and cost-benefit-risk tradeoffs will be completed and R&D on heat exchanger technology and biofouling will be conducted. Criteria will be developed for a possible future test facility. In parallel with the test program, critical components and subsystems will be developed and prescreened so that the most promising candidates can be developed for future large-scale testing.

* * * * *

To launch these multiple technology initiatives, discussed in this chapter, a number of important interrelationships have to be enhanced and/or developed. These efforts are laid out in the following chapter.

Chapter IV—Implementing the Plan: Interrelationships Among Energy RD&D Participants

Introduction of new energy technology and the development of new energy resources will directly affect the lives of all Americans and will thus require the concerted action of all private and public institutions. Cooperative efforts are required among the Congress, Federal Government agencies, state and local governments, regional organizations (e.g., regional governors' conferences), the private sector (e.g., industry, universities, and other nonprofit institutions), and the public. In addition, because of common energy interests and problems, because of the need to cooperate on the resolution of those problems, and because of the impact that new energy technology will have throughout the world, many nations will need to interact with the U.S. as the Plan is executed.

The role of the private sector is paramount. Indeed, one of the basic principles upon which the Plan is formulated is that the private sector and market forces represent the most efficient means of achieving the Nation's energy goals.

The Federal Government will provide leadership and assistance in several ways to help create the overall climate and develop the specific incentives needed to achieve national energy goals. First, it will encourage maximum private sector interaction and involvement in energy RD&D. Second, it will initiate energy RD&D efforts where the private sector is unable to achieve national energy goals; it will **not** manage or fund programs that the private sector can pursue profitably on its own. Moreover, the higher risk programs managed by the Federal Government will be brought to the point of commercial feasibility as rapidly as possible, but will not proceed unless the private sector becomes increasingly involved as the programs approach commercial feasibility. Third, the Federal Government will work to establish a consistent developmental and regulatory framework that balances the early development of alternative technologies with other legitimate public needs such as human health, safety, environmental protection, and economic regulation. Fourth, the Federal Government will seek to involve state and local governments, regional energy organizations, and the public at large in the planning efforts necessary to validate and implement the Plan.

State and local governments and regional organizations are involved in the energy problem because its solution is regional as well as national. Specifically, various localities and regions are affected differently by energy shortages, by large energy projects, and by environmental discharges or conditions. While individual states and regional groups of states are affected differently, in terms of cost and benefits, by some new energy programs, none can take precipitous action without affecting other regions. Moreover, to the extent that state and local governments perform energy planning, they have the primary responsibilities in the related areas of environmental control and human health; resource extraction; plant siting; promulgation of construction and building codes to accommodate innovative technologies; and industrial regulation.

Thus, one of the roles of state and local governments and regional organizations is to reflect these regional and local perspectives in the development of coordinated energy RD&D policy and planning.

The involvement and understanding of the public are necessary to achieve the objectives of the Plan. Since the public is the ultimate consumer of energy, its concerns for the environment, human health, and safety must be considered as carefully as technical and economic concerns. In addition, the public has a major role since it must reach literally millions of individual decisions to implement a truly effective conservation program as well as other elements of national energy RD&D policy.

Finally, international agreements are necessary to coordinate the energy efforts of countries conducting major efforts in RD&D. Benefits can be derived from coordinated international energy RD&D planning and the sharing of capabilities. This RD&D ap-

proach will complement broader efforts of international cooperation in energy policy and planning.

In view of the specific, important roles that government, the private sector, and the public at large must play in achieving the goals of the National Plan for Energy RD&D as well as the benefits provided by international efforts, it is clear that an important aspect of implementing the Plan must be the development of appropriate mechanisms to ensure the participation of and interaction among these entities. To this end, actions are being taken to:

- Develop international agreements
- Improve Federal agency interaction
- Strengthen the private interface
- Expand interaction with state and local governments
- Establish a regional interface.

Developing International Agreements

The United States is not alone in dealing with the continuing problem of a secure and economical energy supply. Many countries in the world have the same problem but, in most instances, are not blessed with natural resources as abundant and diverse as those of the United States. Thus, they, too, have recognized the need for and value of effective conservation programs and the necessity of developing new technologies.

Because of the obvious economic benefits that would accrue, it is clearly in the best interests of all the nations who share the problem to cooperate in finding its solution. The U.S. policy is to promote such cooperation and interaction wherever appropriate.

To this end, ERDA, the Department of State, and other Federal agencies are fostering international research, development, and demonstration initiatives in many energy areas. Several courses of action are being pursued, including: (1) entering into bilateral RD&D and nuclear supply agreements; (2) participating in the International Energy Agency (IEA); (3) providing assistance to developing countries; and (4) participating in the Safeguards Program.

Entering into Bilateral Agreements

More than 30 bilateral agreements are in effect that permit technical data exchanges as well as the supplying of nuclear reactors and uranium enrichment services.

Specific energy RD&D agreements exist between the U.S. and the U.S.S.R., and between the U.S. and Japan. Specifically, the U.S. currently exchanges information on breeder reactors with Japan, and in the fields of fusion and breeder reactors with the U.S.S.R. A number of agreements in the nonnuclear area are pending with Japan. The U.S. has entered into separate agreements with Iceland and Italy in the geothermal field, and has agreements with Poland on coal research. Energy RD&D cooperation also forms an important part of numerous other general Science and Technology Agreements with other countries. Finally, the U.S. has recently executed memoranda of understanding (MOUs) with eight countries calling for information exchange on solar heating and cooling of buildings.

Participating in the International Energy Agency

As a result of membership in the International Energy Agency (IEA), the U.S. is participating in a number of energy RD&D programs. For example, active efforts have been under way during the past year to identify areas of interest for cooperation, to prepare a framework of principles governing joint support of energy RD&D projects, and to draw up cooperative implementation agreements. In the coming year, work will proceed on producing an overall IEA strategy by the end of 1976.

In addition to these policy and administrative activities, the IEA has launched a number of specific, important energy technology RD&D projects. Originally, nine areas were identified for multilateral cooperation: coal technology, nuclear reactor safety, radioactive waste management, controlled thermonuclear fusion, conservation R&D, solar energy, hydrogen, municipal and industrial waste, and waste heat utilization. At special meetings on research and development on November 20-21, 1975, the IEA Governing Board recommended seven new areas: high temperature reactors for process heat, geothermal energy, solar power systems, wave power, wind energy, ocean thermal energy, and biomass conversion. The IEA also approved an energy systems analysis effort, which will be a major activity in 1976, to identify and evaluate energy technology options, their potential energy contributions to the various member countries, and their commercial implementation time frame; and to advise the member nations individually and collectively on RD&D priorities. This systems analysis work will be undertaken by national experts and by two international groups, one located at the Brookhaven National Laboratory in the U.S. and the other at the Julich Laboratory in Germany. In the course of these studies, data on energy and interfuel substitution possibilities will be collected and made available to all member nations.

Similarly, cooperative ventures among smaller groups of participating countries can be arranged under the auspices of the IEA. For example, in November 1975, the U.S. signed the five agreements as part of an overall IEA coal technology cooperative effort. One of these was an agreement among the United States, the Federal Republic of West Germany, and

the United Kingdom to research more efficient and cleaner ways to burn coal. A fluidized bed combustion test facility, designed to burn coal more efficiently, will be built in Britain at a shared cost of $15-20 million.

Assisting Developing Countries

The U.S. participates in a number of international, energy-related activities that involve developing countries. For example, there are U.S. Joint Cooperative Commissions with Israel, Iran, and Egypt that allow for assistance in nonnuclear programs.

On September 1, 1975, during the special meeting of the U.N. General Assembly, the U.S. proposed an International Energy Institute (IEI) to assist developing countries in applying available energy technology to their energy needs. This concept was welcomed by other members of the U.N. and is now in the process of being developed in more detail. In the nuclear area, the International Atomic Energy Agency (IAEA) provides an excellent forum for cooperation and mutual reward among developed and developing nations. Two notable programs in this format are the IAEA's technical assistance program and its Safeguards Program.

Participating in the Safeguards Program

The International Atomic Energy Agency (IAEA) is responsible for the implementation of safeguards portions of the Nonproliferation Treaty relating to the peaceful uses of nuclear materials. In the Safeguards Program, the United States and other countries supplying nuclear material, equipment, and technologies require assurances that: (a) exported nuclear material is not diverted by the receiving country for explosive use; (b) receiving facilities have adequate safeguards and physical protection against domestic nuclear threats; and (c) any nuclear assistance will not be used by the receiving country to further any military purpose.

ERDA, the Arms Control and Disarmament Agency (ACDA), and the Nuclear Regulatory Commission (NRC) assist the IAEA in developing effective safeguards procedures and improving measurement techniques. ERDA is responsible for reviewing facilities that receive U.S. nuclear materials to ensure adequate physical protection before NRC grants the export license. These ongoing reviews have proved effective in encouraging adoption of these measures by other countries.

Improving Federal Agency Interaction

Effective Federal agency interaction in energy RD&D is essential to: (a) integrate the goals and objectives of RD&D into the broader context of national energy policy; (b) eliminate redundancies or gaps in energy RD&D planning and implementation; (c) accelerate the RD&D process and the market penetration of new energy technologies and systems by minimizing procedural delays and integrating tasks performed by different agencies; (d) optimize Federal resources (money and manpower) and thereby improve RD&D productivity in the Federal sector; and (e) fulfill legislative and administrative requirements expressed in Congressional mandates and joint agency agreements. Of these objectives, the two that must be vigorously pursued first are the: (1) integration of energy RD&D programs into the broader context of national energy policy, and (2) elimination of unintended redundancies or gaps in energy RD&D planning and implementation.

Integrating Energy RD&D Programs into National Energy Policy

Energy RD&D goals and objectives must be integrated into the broader context of a national energy policy. This necessitates interaction and coordinated program planning not only among the Federal agencies that are charged with RD&D, but also among all Federal, state, or local agencies as well as legislative bodies that will implement national energy policy. The Energy Resources Council (ERC) is the primary instrument for this coordination. The ERC ensures communication and coordination among the several agencies involved in developing and implementing energy policy or in managing energy resources.

Among all the Federal agency interactions affecting energy RD&D, perhaps the most important is that between ERDA and the Federal Energy Administration. It is here that a strong tie is established at the working level between national energy policy and national energy RD&D policy. ERDA's focus is the technological character of the energy system, while FEA's focus is the economic (price regulatory) and operational aspects of the energy system. The activites of the two agencies do, of course, overlap and complement each other.

In addressing technological problems, ERDA must recognize the possible institutional and social barriers to implementation of both existing and new technologies and, hence, must interact strongly with FEA as the companion agency that can mount attacks on such problems. In modifying the present energy system, FEA should recognize the existence of technoiogical issues and, hence, must interact strongly with ERDA, the agency that can mount attacks on such problems.

The nature and importance of these interactions have been more and more strongly recognized by FEA and ERDA over the past year. As a result, the two agencies have agreed to increase their emphasis on joint program planning activities. Mutual involvement in the early phases of program planning will

help ensure development of fully coherent national programs. Responsibility for implementing the programs will follow both the legislative direction provided the agencies and the capabilities in place in each agency to direct and integrate such activities with its related activities. ERDA and FEA are presently developing a memorandum of understanding (MOU) that will embody these principles and provide an overall framework for more detailed coordination on specific programs.

Of similar importance is a strong and interactive relationship between ERDA and the Environmental Protection Agency (EPA). This relationship is needed to assist ERDA in effectively integrating its approach to environmental consideration into technology design and to ensure a coordinated Federal approach to key environmental issues.

Eliminating Redundancies in Energy RD&D Planning and Implementation

Because of its scope, complexity, and number of participants, the Nation's energy RD&D program has the potential for significant redundancies and gaps if interaction and coordinated program planning and management are neglected. To avoid energy RD&D program redundancies and gaps and to ensure the coordinated implementation of the National Plan for Energy RD&D, three kinds of actions are being taken:

- **Obtaining input to Volume II of this Plan from other agencies involved in energy RD&D.** In assembling Volume II of the Plan (which describes in detail implementation plans for the total Federal energy RD&D effort) each year, ERDA interacts with the various primary agencies involved in energy RD&D. Specifically, other agencies review relevant sections of Volume II; examine the integrated program for omissions and overlaps; and provide feedback to ERDA on the results of their reviews.
- **Entering into formal agreements with other Federal agencies.** Some of the formal agreements that have been reached in the past year or will be implemented in the near future are of particular importance:
  - —**A memorandum of understanding (MOU) between ERDA and the National Aeronautics and Space Administration (NASA)** to perform basic and applied research at selected NASA centers in specified disciplines and technologies (e.g., photovoltaic systems, gas turbine technologies, fuel cell technology, hydrogen technology, wind-energy systems).
  - —**An MOU between ERDA and the National Bureau of Standards (NBS)** to cooperate in identifying and evaluating specific programs related to measurements and standards in fossil energy, environment and safety, solar energy, geothermal, advanced energy systems, national security, conservation, and other RD&D programs. Under a separate agreement, NBS will conduct an independent evaluation for ERDA of energy-related inventions to provide information on promising ideas that have been examined for their technical feasibility and worthiness for consideration for further support.
  - —**An imminent agreement between ERDA and the Small Business Administration (SBA)** to ensure small business concerns are provided a reasonable opportunity to participate fairly and equitably in Federal grants, contracts, purchases, and other activities related to energy RD&D.*
  - —**Agreements between ERDA and the Department of Defense (DOD)** to perform RD&D and support ERDA progress in areas such as solar heating and cooling, solar electric, ocean thermal, bioconversion, geothermal, and synfuel evaluation. A joint ERDA/DOD effort is planned to identify additional areas in which joint efforts will be mutually beneficial. A general MOU between ERDA and DOD is being prepared.
  - —**Four impending MOUs between the Nuclear Regulatory Commission (NRC) and ERDA** to provide for coordination between the two agencies on the Safeguards Program operational policy, contingency plans, and international responsibilities; Safeguards RD&D and testing activities; Emergency Preparedness response resources; and the sharing of nuclear materials information.
  - —**An imminent MOU between the Department of Housing and Urban Development (HUD) and ERDA** to coordinate activities pertaining to energy-related housing and urban programs.
  - —**An MOU between the Water Resources Council (WRC) and ERDA** to assess water resource requirements and water supply availability for energy technologies that are the subject of Federal RD&D efforts. The agreement calls for the establishment of a water-for-energy base program at the WRC, participation in ERDA's environmental and water resource assessments, and exchange of data between ERDA and the WRC. Initial involvement will emphasize programs in synthetic fuels, geothermal energy, and coal conversion demonstration plants.

* ERDA is also supporting a symposium in Washington, D.C., on March 24–25, 1976, under the auspices of the American Association of Small Research Companies, entitled "Opportunities at ERDA for Small R&D Companies."

- **Participating in the Federal Energy Management Program (FEMP).** The Federal Government itself is a significant energy consumer, representing over 2 percent of total national energy consumption. The Federal Government is also the largest single purchaser of energy in the Nation, thus providing a significant opportunity for direct savings and leadership in energy conservation.

  The Federal Energy Management Program was established in 1973 to achieve major reductions in Federal department and agency energy consumption. In 1974 and 1975, annual energy savings of approximately 25 percent were achieved, primarily through curtailment measures such as adjusting thermostats and lighting in Federal facilities and eliminating wasteful practices in the operation of ships, planes, and automobiles.

  This program has now been extended for 10 years to reduce energy use in the Federal Government through adoption of cost-effective technological improvements in Federal facilities. It is also expected to have the "spin-off" benefit of demonstrating life-cycle cost-effectiveness of conservation technologies not now in the marketplace. Developed under the policy guidance of the Energy Resources Council (ERC),* the program will be undertaken by:
  - —FEA, which is responsible for management leadership
  - —ERDA, which oversees the technological aspects of the program
  - —GSA, which is charged with ensuring appropriate program implementation.

Strengthening the Private Interface

Decisions on energy RD&D programs will affect the life of every citizen and every institution in the country. Thus, all citizens should have the opportunity to influence those decisions. However, there are many "publics" who have interests—often conflicting interests—in energy RD&D. Other difficulties include the technical nature of the subject of energy; the long lead times involved in planning; the complexity of the energy-field participations and mission; and the proprietary nature of some of the information.

Ensuring that public opinion is represented in energy RD&D planning and obtaining support for implementation of its results require a two-way dialogue between informed citizens and receptive decision-makers. Government decision-makers must provide the public with timely and complete information, including background materials on the problems, needs, and concerns of energy RD&D programs and planning; possible solutions to the problems; and possible effects (social, environmental, economic, technological) of the programs, problems, and solutions. The informed citizens must be provided with and take advantage of various communications forums, including those listed in Table IV-1. Among the most important of these avenues of communication are:

- **Advisory committee.** ERDA has a number of advisory groups made up of individuals who represent a broad spectrum of technical expertise and citizen interest. The General Advisory Committee maintains a broad overview of ERDA's programs; seven other advisory committees deal with specialized areas: Advisory Committee on Geothermal Energy, General Technical Advisory Panel (Fossil),

Table IV–1 Forums for Interaction

Interests Affected	Primary Forum for Soliciting Review and Comments
The general public, industry, state and regional energy representatives, special interest groups, and the academic community	• Advisory Committees • Consumer representation plan • Public hearings and meetings • Meetings with ERDA officials • **Federal Register** requests for comment • Publications and speeches • Environmental impact statement
The Congress	• Legislative hearings on ERDA-related programs and budgets • General Accounting Office reviews and other special study requests • Formal review of the National Plan for Energy RD&D by OTA and CEQ*
Other Federal agencies	• Joint planning activities throughout the year • Review of the Plan prior to publication and response to a formal ERDA request for programmatic information** • Environmental impact statement

* Subsequent to this action, the Energy Policy and Conservation Act (P.L. 94–163) mandated a 10-year conservation program for buildings owned or leased by the Federal Government. A part of the FEMP program will address this requirement.

* As stated in the enabling ERDA legislation, the Council on Environmental Quality (CEQ) is required to undertake an ongoing assessment of the adequacy of attention to environmental protection and energy conservation in the energy RD&D program. The Office of Technology Assessment (OTA) has also been requested by Congress to undertake a review of the annual report.

** See ERDA 76–1, Volume 2—**Program Implementation**, for other agency details on specific programs.

Historical Advisory Committee, Senior Utility Steering Committee, High Energy Physics Advisory Panel, Lignite Advisory Committee, and Atomic Energy Labor-Management Advisory Committee. Meetings of these groups are announced in advance and are open to the public.

- **Public hearings and meetings.** ERDA holds and participates in many public hearings, meetings, and conferences. For example, ERDA has initiated a series of regional public meetings to solicit comments on the National Plan for Energy RD&D in general and on the implementation of the Plan for the regions in which the meetings are held in particular. From these, important relationships are developed with concerned interest groups and state and regional policy makers. As a result of one of the early public meetings, ERDA will be supplied with a continuous flow of information and viewpoints from 16 southern states on the National Plan for Energy RD&D.

  Primary responsibility for conducting these meetings is being assigned to the regional ERDA organization, with the aim of establishing these offices as accessible contact centers. Public meetings will continue after the publication of the Plan to discuss its contents and its impact on the Nation from a regional and local perspective. Meetings have already been held in Atlanta and Seattle, and are being planned for Denver, Chicago, San Francisco, and Boston.
- **Environmental impact statements.** Programs to apprise the public and organized interest groups of the estimated environmental characteristics of alternative prospective energy systems and to provide open channels for responding to specific public concerns in the decision process are available. This communication is basically implemented through publication of environmental impact statements and through their associated public hearings.

  Environmental RD&D activities are directed through a sequential process, tailored for each energy alternative. At milestones in this process, where actions may be proposed that would significantly affect the quality of the environment, environmental impact statements are prepared. Environmental impact statements may be generic (program) or site-specific (project) in nature, depending on the state of technology development and nearness to demonstration. They explore sociological, aesthetic, and other public concerns and provide a basis for public review and discussions to ensure public input to the energy development process.
- **Consumer representation plans.** Interaction with the public at large can be the most difficult dialogue to establish but can also be the most rewarding as the public's concern for human health, safety, the environment, style and quality of life, and economic climate are paramount in a democratic society. Comprehensive consumer representation plans are being developed by all major Federal agencies to provide specific channels for consumer participation in major Federal-agency policy and program decisions. This effort is in response to the President's call for an examination of present and new procedures by which all consumers can receive an equal opportunity of being heard. Preliminary consumer representation plans have been published* and, after comments have been received in writing and at a series of public meetings, will be made final in 1976.

  ERDA's Consumer Representation Plan is being designed to ensure ERDA takes into consideration the effects of its programs on a multitude of consumers. Participation of energy consumers and producers in the decision-making of the agency is both necessary and desirable. ERDA's job is to assist private industry in the development of new or improved technologies that can be made commercially attractive. This implies the technologies must meet the requirements of the private marketplace in terms of needs, institutional compatibility, economics, and the requirements of the general welfare (i.e., environmental and social acceptability). Neither ERDA nor the Federal Government as a whole controls the marketplace or the Nation's environmental and social standards; in the final analysis, it is the consumer who does, through buying practices and the political process. For the consumer to participate in this decision-making process, he must know:

  —What decisions are planned, when they will be made, and who will make them

  —The technical, economic, environmental, and institutional facts and assumptions available to the decision-maker

  —The alternatives under consideration by the decision-maker

  —The analytical tools, methods, and results that are being used to assist in the decision making process.

  An informed public can influence the Federal decision-making process if it can bring to light new or additional facts or assumptions, raise workable new or different alternatives, and provide new or additional analytical results. The ERDA Consumer Representation Plan is designed to ensure this flow of opinion and information.

Although these communication forums are generally available to all citizens and all institutions, specific avenues are being explored and important policy initiatives are being taken to establish specific interaction with industry and universities.

* **Federal Register**, Volume 40, No. 229, November 26, 1975.

Table IV–2 Illustrative Jointly Funded Programs With Industry *

Program Area	Industry Participant	Percent of Total Estimated Cost Contributed by Industry
A. Fossil		
1. High-BTU Gasification		
a. Bi-Gas Pilot Plant	American Gas Association	32
b. Steam-Iron Pilot Plant	American Gas Association	33
2. Gas and Oil Extraction		
a. Miellar Polymer Flooding	Oil companies	65
b. Thermal Recovery and Solvent	Oil companies	52
B. Conservation		
1. Electric Energy Systems		
a. Battery Energy Storage Test Facility	Utility companies	54
b. Forced Cooling Test	Electric Power Research Institute (and a manufacturer of underground electrical equipment)	76
2. End-Use Conservation		
Stirling Engine–100 H.P.	Automobile manufacturing company	50
C. Fission		
Clinch River Breeder Reactor	Utility companies (and some reactor manufacturers)	14
D. Geothermal		
Thermal Loop Experiment with Hot Brines	Utility company	50

* See Table III–6 for the estimated total cost-sharing with non-Federal organizations.

Interaction with Industry

The ERDA mission is unique. Unlike other government agencies involved in RD&D, ERDA's mission is to research and develop new technologies and to assist the private sector in penetrating the market with their new technologies. To this end, ERDA programs are designed to involve industry at the earliest possible point in the RD&D process.

The traditional route of technology research and development is from basic and applied research laboratories and individual inventors through engineering facilities to the producers of goods and services for use by all consuming levels. It is obvious that industry, both large and small, is crucial to this process as the developer, producer, and marketer. Thus, the Federal Government/industry interface is as broad as industry itself.

Various forums are used to communicate with American industry. (See Table IV-1.) In addition, as shown in Table IV-2, ERDA is seeking jointly funded or jointly planned programs with industry and industrial organizations* to establish working relationships at the earliest possible developmental stage of new energy technologies.

* For example, a memorandum of understanding is imminent between the Electric Power Research Institute and ERDA to jointly review program plans, coordinate future activities, identify projects appropriate for coordinated parallel or sequential contracting, and identify efforts appropriate for joint funding.

ERDA, along with other government agencies, is also conducting a study to determine how the existing patent and licensing policy can be applied most effectively to enhance the private sector's incentive to engage in energy RD&D. Public meetings have been held at which much helpful criticism has been received from various industry representatives and public interest groups. An interim report was recently submitted to Congress, and **it is ERDA's intention to complete the patent policy study and to deliver a final report to Congress in 1976.**

The financial community has a critical role in the market penetration of new energy technologies since it is from this sector that much of the funds for RD&D investments will come. Without the financial backing of the banking and investment institutions, very few new energy technologies will come into general use. But before making the necessary loans, the financial community must be assured of the technical success of the energy option, its ability to capture a large enough share of the market to become profitable, and a government regulatory climate that will not impede or prevent market penetration of the technology. It is, therefore, imperative that ERDA maintain close liaison with the financial community to communicate the status of the energy RD&D programs and of government attitudes and, in turn, to understand the concerns and attitudes of the investors. During this year, ERDA will initiate such a relationship.

No summary of efforts to strengthen the relationships with industry would be complete without mention of the government's commitment to small business. Specifically, all government energy RD&D program managers aggressively seek out small business participation, and small companies are made aware of the existing project opportunities. In addition, an ERDA task force has been established to coordinate and monitor small business participation, and a cooperative agreement with the Small Business Administration is being readied for signature. Likewise, individual inventors will be assured full evaluation of their energy-related projects through a joint program of ERDA and the National Bureau of Standards.

Liaison with industry is also being furthered through the use of technology utilization representatives located in eight of the National Laboratories throughout the country. These representatives serve as local and regional points of contact with private industry on the availability of technologies, particularly those evolving from energy programs but having nonenergy applications.

Finally, the Office of Industry, State and Local Relations (ISL) advises ERDA programmatic and "corporate" management on better ways to obtain and use industrial views in the ERDA decision-making process. To this end, the ISL staff is in frequent communication with all segments of industry, with ERDA energy RD&D program offices, and with state and local governments. Since representatives of these groups frequently share common interests in energy resource development implications, this centralized organizational unit represents the interest of these groups in planning and policy formulation. Also, ERDA recently established an Office of Commercialization that is responsible for:

- Continuing the analyses and initiating program implementation efforts related to the synthetic fuels commercial demonstration program
- Identifying major constraints to commercialization of other selected energy technologies and analyzing the effectiveness of various incentives (such as in the Nonnuclear Act) in overcoming these constraints
- Examining mechanisms for speeding the introduction, in the near-term, of available energy technologies into the marketplace.

Interaction with Universities*

The Nation's academic community represents an important resource needed for the conduct of supporting research and technology development across the spectrum of energy RD&D, as well as a major contributor to the development of adequate manpower resources.

During FY 1975, contracts approximating $135 million** were signed with universities. ERDA expects this figure to climb to about $140 million** during FY 1976 and $170 million** in FY 1977.

ERDA is building on this base to establish a broad and effective partnership with universities in conducting research, training and developing skilled manpower, ensuring local concerns are incorporated in the National Plan, and strengthening the traditional role of universities in research and teaching. To this end, ERDA is in the process of developing a university program. The specific policy considerations for the effort are:

- Universities and colleges throughout the country will be encouraged to participate in the Nation's energy research programs to the maximum extent of their capabilities and interest.
- University activities supported by ERDA will be relevant to ERDA's mission and compatible with the interest, strengths, and activities of the university.
- ERDA will encourage participation in supported research by young faculty members and by students, as well as senior investigators, in ways that enhance and strengthen the universities' traditional educational and research mission.
- Team research of both an interdisciplinary and a multi-disciplinary nature on the part of faculty and students will be encouraged on appropriate scientific and technical related subjects, and on the broader social assessment of energy development and utilization.
- ERDA recognizes and will provide support to the extent practicable to the universities' primary educational role of training professional manpower to meet current and long-range energy needs.
- ERDA will encourage the submission from university investigators of unsolicited research proposals that are consistent with the specific mission and objectives of the program.
- Cooperative efforts among the universities, industry, and ERDA's National Laboratories and Energy Research Centers will be encouraged.

An ERDA University Conference was held in early November 1975 to acquaint universities with ERDA's programs and plans and to encourage open dialogue and feedback. Followup meetings are contemplated, as is the establishment of a University Advisory Committee to provide input on matters related to the ERDA/university interface.

* All nonprofit institutions of higher learning and educational nonprofit organization that are operationally affiliated or integrated with such institutions.

** Excludes funds (e.g., about $750 million for operating expenses in FY 1976) paid to universities and university consortia that operate ERDA facilities.

Expanding Interaction with State and Local Governments

State and local governments and regional groups are well aware of the Nation's energy problems and have major responsibility for finding their solutions. Their perceptions of the problems, the candidate solutions, and the possible local and regional impacts must become an integral part of the planning process for the energy RD&D program.

State and local governments can contribute significantly to energy RD&D projects by providing the general public with the information necessary to obtain sociopolitical consensus on energy matters and by encouraging the conservation ethic not only for energy but also for other natural resources. They frequently have the tools—taxation and siting authority—to ameliorate some of the inequities brought about by new technologies. These government units can make significant contribution in other ways as well; for example, 38,000 units of local government utilize enormous numbers of buildings, vehicles, and equipment and are among the largest energy consumers in the Nation. They can take the lead in implementing technology improvement and conservation methods. In addition, numerous municipalities are producers as well as consumers of electrical power, thus they have an immediate and direct interest in the execution and eventual implementation of RD&D projects.

Among the roles these organizations have are:

- Identifying the environmental, social, and economic impacts of energy projects within their geographical jurisdictions
- Developing and promulgating, when appropriate, revised local standards, taxing policy, and other incentives (such as construction and land-use planning) that facilitate and encourage energy conservation, the use of new fuel sources, and the expansion of the supply of existing sources
- Defining questions, problems, and alternative solutions with respect to resource extraction, transportation, and distribution
- Helping provide information and data to assist the public in arriving at an informed sociopolitical consensus on energy matters
- Participating in national energy RD&D planning
- Conserving energy in providing services and in operating government facilities within their jurisdiction.

Technical assistance is being provided to many state governments through the technology utilization program mentioned earlier. Technical representatives located in eight of ERDA's National Laboratories attempt to match state needs with technology available at the laboratories. The National Laboratories are working on regional assessment studies that will predict and evaluate the socioeconomic, environmental, and social impacts of energy resource developments. State governments are actively cooperating in these studies.

A regional studies program is being conducted to predict and evaluate the socioeconomic, human health, environmental, and institutional impacts related to the development of all on-line and prospective energy sources. Six ERDA laboratories are coordinating this program on a regional basis and have direct contact with state governments. This program provides not only information to ERDA on potential environmental issues but also feedback to the states for use in energy policy decision-making.

The states are already actively engaged in examining energy RD&D and broader energy matters. For example, under the National Governors' Conference, five subcommittees have been formed to deal with national coal policy. These subcommittees and their chairmen are: Surface Mine Reclamation, Governor Arch Moore (West Virginia); Water Requirements for Coal, Governor Richard Kneip (South Dakota); Coal Gasification/Liquefaction, Governor Dan Walker (Illinois); Coal Transportation Problems, Governor Julian Carroll (Kentucky); and Boom/Ghost Towns and Financial Problems, Governor Richard Lamm (Colorado). This work is being coordinated with the newly created Intergovernmental Coordinating Committee formed under the auspices of the Energy Resources Council. This committee will serve as a center for interaction among Federal, state, and local government officials in developing national energy policy, and is already working on synthetic fuels policy and coal policy. Specifically, the new committee will facilitate Federal interagency coordination for national energy programs. It will also provide a vehicle wherein state and local governments and their regional and national associations can be informed and consulted as policy plans are developed to ensure adopted policies will have the flexibility to fit various geographical situations.

Beyond participating in energy RD&D policy formulation and technical information activities, states and localities are carrying out specific energy RD&D projects. For example, the states of Texas and Louisiana are studying the characteristics and development potential of geothermal energy along the Gulf Coast. The City of Albuquerque, New Mexico, is involved in research on a pilot plant for thermoradiation of sewage sludge, while the City of Hobbs, New Mexico, is working on a community-wide energy management plan in cooperation with the University of Oklahoma.

The strengthening of Federal ties to regions, states, and localities is essential to the achievement of national energy RD&D goals. To this end, ERDA is actively building new relationships with regional bodies and with state energy offices. Workshops covering specific technology areas are now being

planned. Information packets are being distributed regularly to all 50 states to keep state officials apprised of national energy RD&D policy and programs. Several technology transfer programs that would bring the Federal Government and the state together in a variety of cooperative activities are now under consideration. This increasing interchange will clearly result in greater input to and consensus on the National Plan for Energy RD&D.

Establishing the Regional Interface

The domestic energy problem and its solution are national, regional, and local in nature. The problem extends beyond traditional RD&D efforts and includes, as an essential ingredient, the market penetration of near-term technologies. Success or failure in meeting the Nation's energy needs will depend as much on the ability to resolve complex economic, social, political, and ecological issues at the regional and local levels as on the technical quality of the specific energy RD&D programs. The Federal Government must therefore be sensitive to local and regional needs. It must also reach public and private groups at these levels to provide information to them; to develop effective, productive communication links with regional, state, local, university, financial, and industrial representatives; and to receive feedback from them on the problems, progress, public acceptability, and overall effectiveness of ERDA's programs and the National Plan for Energy RD&D. To assist in achieving ERDA's overall energy mission and in carrying out its specific assigned energy pro-

Figure IV–1 ERDA National Organization

gram responsibilities, an enhanced regional capability may be desirable.

ERDA is a nationwide organization (see Figure IV-1) created by the Energy Reorganization Act of 1974 from a combination of Federal energy RD&D units formerly residing with the Atomic Energy Commission, Department of the Interior, National Science Foundation, and the Environmental Protection Agency. These diverse elements brought with them considerable headquarters and field resources and a variety of management practices.

ERDA is composed of a headquarters facility consisting of approximately 3,000 people, and a nationwide field organization consisting of approximately 95,000, of which more than 90,000 are operating contractor employees. This field organization consists of:

- 55 laboratories and production facilities, with the major operating contractors including universities, university consortia, nonprofit organizations, and private industry. These facilities, most of which emanated from the former AEC or the DOI's Bureau of Mines, include 8 major multiprogram laboratories, 5 Energy Research Centers, 6 engineering laboratories, 7 specialized physical research laboratories, and 13 specialized biomedical research laboratories. There are also 9 nuclear material processing plants and 7 weapons production and testing facilities engaged in carrying out ERDA's important national security responsibilities
- 8 government-staffed field Operations Offices—from the former AEC. These Operations Offices are responsible primarily for contract administration, management, and review. This includes responsibility for administering the operating contracts for the government-owned, contractor-operated (GOCO) facilities in their region. Some Operations Offices also have direct operational responsibilities and, in a few cases, fulfill program management and execution functions.

The diversity of this interface and ERDA's role to assist the private sector in introducing new technologies to the marketplace, among other things, necessitated a management assessment of field resource utilization.

As a first step in this assessment, ERDA established an ad hoc group of experienced R&D managers from industry, academia, and the ERDA field structure to conduct a Field and Laboratory Utilization Study.* Based in part on the study group's recommendations and on other management considerations, ERDA is studying possible organizational and management actions, including:

- Delegating project execution authority to the field, on a case by case basis
- Assigning specific mission responsibilities to selected laboratories and Operations Offices
- Developing a coordinated approach to marshal the various technical resources in each region to help ERDA attain its energy research, development and demonstration objectives

Several task forces are now under way and will be reporting their findings and recommendations to ERDA management. These task forces must consider both the benefits and the consequences of such actions. In addition, alternative approaches, staffing and other resource implications, and possible disruptions during a transition period must be defined and evaluated. ERDA is taking initial actions, where they appear appropriate, to increase field responsibilities, but the scope and timing of these and possible future changes require and will receive careful review.

* The results of this independent study are contained in ERDA-100, **Report of the Field and Laboratory Utilization Study Group**, December 1975.

Chapter V—Implementing The Plan: ERDA Planning System

Under the Energy Reorganization Act of 1974*, the Federal Nonnuclear Energy Research and Development Act**, and several other statutes, ERDA is assigned planning responsibilities that extend beyond those necessary to formulate the programs that the agency conducts directly. One of ERDA's major responsibilities is to update its National Plan for Energy RD&D annually. Recognizing that its planning responsibilities have impact on other Federal agencies, industry, and the public, ERDA believes it is important to document the Planning, Programming, Budgeting, and Review (PPBR) system it is developing to discharge its statutory mandates.

The overall objective of ERDA's PPBR system is to provide an integrated and disciplined approach to analyzing the Nation's future energy technology needs; formulating the Federal role in addressing those needs; designing targeted programs to conduct ERDA's portion of the Plan; allocating resources consistent with the Plan and program design; and ensuring that ERDA's programs are effectively managed. Accordingly, the PPBR system will address major issues such as:

- What new energy technologies should be pursued nationally to meet energy goals?
- To what extent will the private sector develop important technologies without Federal assistance?
- If Federal assistance is involved, what is the role of RD&D in comparison to regulatory, fiscal, or institutional solutions?
- If Federal RD&D is involved, what specific program goals are appropriate, who should manage the program, and at what cost?
- If ERDA is responsible for RD&D, what is the most cost-effective program plan and related budget?

* Sections 2(b), 103(1), and 103(4), among others, of Public Law 93–438.

** Sections 4(b), and 4(c), and 6(a), among others, of Public Law 93–577.

PPBR System Structure

The general features of ERDA's PPBR system are illustrated in Figure V-1. The system comprises analytical, planning, resource allocation, program implementation, and program evaluation activities. The analytical activities provide support for the planning activities, which focus on normative, strategic, and program planning. Strategic and program planning in turn help guide the resource allocation and program implementation activities. Program evaluation activities serve to check actual progress against planned progress and provide a basis for updating and changing planning goals.

Environmental planning is a key part of the ERDA PPBR system; environmental issues (including occupational and human health, safety and welfare, and ecology) are thoroughly considered and weighed throughout the analysis and decision-making process. Accordingly, environmental planning is being embodied in a formal structure within the PPBR to ensure that appropriate environmental RD&D priorities are maintained and that ERDA resources are allocated to produce environmentally acceptable energy technology options.

Planning Activities

PPBR activities focus on three types of planning—normative, strategic, and program—aimed at determining what **ought** to be done, **how** it can be done most effectively, and what **will** be done. Environmental planning is an integral component of these three major planning phases. Accordingly, this section discusses each of the planning phases and then describes ERDA's environmental planning process as it relates to normative, strategic, and program planning.

Normative Planning

Normative planning identifies preferred solutions to the national energy problem; that is, what **ought** to be done. The identified solutions are based on a number of analytic inputs and policy assumptions. As a

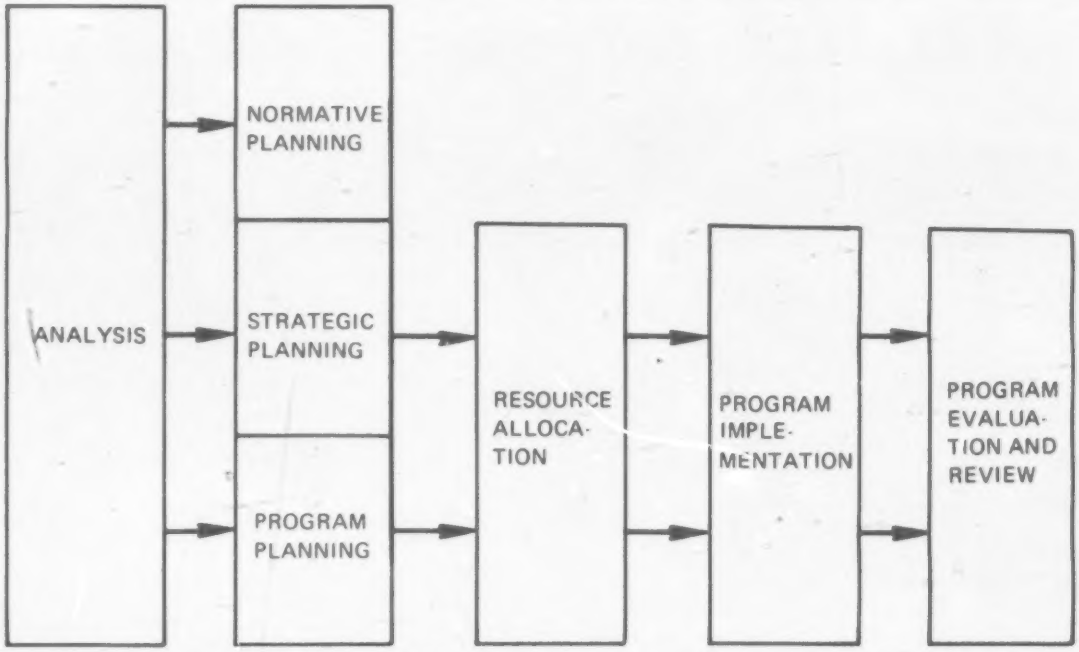


Figure V–1 General Features of PPBR System

first step, reference projections that indicate the future state of the energy system based on existing trends must be established. These projections serve primarily to define future problems and indicate the need for action.

Second, normative analysis involves the development of alternative cases and the use of models that replicate the dynamic behavior of the energy system. A series of cases that span the range of future likely conditions is developed by assigning reasonable values to changes in parameters such as resource availability, technological developments, absolute and relative costs of various fuels and technologies, environmental standards, status of control technologies, population distribution and makeup, GNP and its components, capital availability, industrial process, labor productivity and life styles. These cases developed will suggest alternative directions for the evolution of current energy system through time and define objectives toward which new strategic approaches and policy development could be oriented.

Examination and comparison of the cases can provide insights into policies, technologies, or other factors that are important regardless of the Nation's future direction. Normative analysis also identifies problems common to potential futures, defines common needs, and indicates the probable market size and likely timing range for new technologies. The reasonableness of these cases can be tested and the impact compared of any inhibiting constraints (e.g., resource, manpower, and financial requirements, regulatory processes, national interests and security, legal restrictions, institutional barriers, prevailing sociopolitical moods).

Once consequences of alternative cases have been assessed, choices can be made and action directed toward the ends that such choices dictate. **Thus, normative planning is not directed towards prediction, but rather towards goal-setting.**

Strategic Planning

Strategic planning defines how the goals outlined in the normative planning phase can be achieved most effectively. At the strategic level of planning, both the specific energy system options and the constraints to their market penetration must be analyzed in much greater detail than they were in the normative phase.

The keystone of strategic analysis is the replication of the private sector decision-making process to determine appropriate private and public sector roles. To the maximum extent possible, the analysis is based on a quantitative assessment of benefits, costs, and risks. Furthermore, the analysis must employ decision criteria and roles appropriate for the market sector in which the energy system option will be introduced.

The fundamental logic that underlies strategic planning is illustrated in Figure V-2. The private sector is the key instrument for achieving market

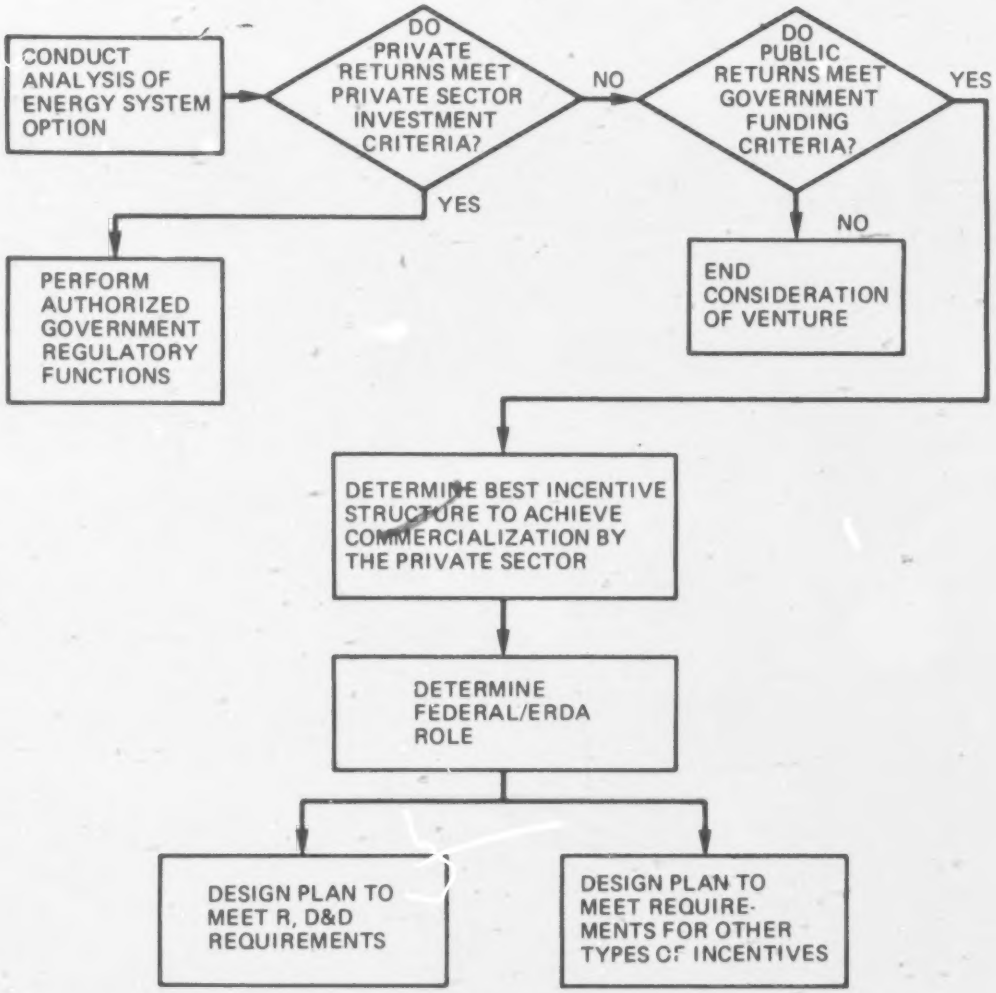

CONDUCT ANALYSIS OF ENERGY SYSTEM OPTION
DO PRIVATE RETURNS MEET PRIVATE SECTOR INVESTMENT CRITERIA?
NO
DO PUBLIC RETURNS MEET GOVERNMENT FUNDING CRITERIA?
YES
YES
NO
PERFORM AUTHORIZED GOVERNMENT REGULATORY FUNCTIONS
END CONSIDERATION OF VENTURE
DETERMINE BEST INCENTIVE STRUCTURE TO ACHIEVE COMMERCIALIZATION BY THE PRIVATE SECTOR
DETERMINE FEDERAL/ERDA ROLE
DESIGN PLAN TO MEET R, D&D REQUIREMENTS
DESIGN PLAN TO MEET REQUIREMENTS FOR OTHER TYPES OF INCENTIVES

Figure V–2 Strategic Planning Logic

penetration of new energy technologies. Government RD&D involvement will be restricted to those energy technologies for which (1) private returns are too low or market barriers too high to induce private sector activity, and (2) public returns are sufficiently high to justify a government role.

If the private rate-of-return and other figures-of-merit for an energy system option do not meet requirements, the venture will not be considered for private funding. If the venture does meet the requirements and it seems likely that the private sector will fund the venture, then the government will perform only its legislated regulatory functions.

If factors that preclude sponsorship of the venture in the private sector are identified (e.g., high risk, high exposure, market fragmentation), it will be necessary to determine if the public rate-of-return is sufficiently high to justify government involvement. If the public rate-of-return is judged to be high, it must then be determined what type of government involvement is appropriate. The Federal Government can use various incentives (e.g., guaranteed loans, capital grants, price supports, research and development funding) to induce the private sector to innovate or to accelerate the rate of introduction of new products in the marketplace. The most effective incentive(s) can be determined by repeating the private sector decision analysis and determining which incentives result in the venture meeting the private sector's investment criteria. Those incentives most likely to induce private sector participation at the least cost to the government can then serve to define the primary government role.

Outputs of the strategic planning process in-

clude a listing of energy system options ranked according to their relative importance within the ERDA program, and a definition of ERDA activities and resource levels required to assist the private sector in the market penetration phase of the various energy systems. These outputs provide the basis for long-term (e.g., five-year) resource allocation among the various strategic alternatives.

Program Planning

Program planning describes the detailed means by which the ERDA program defined in the strategic planning phase will be implemented. Decisions are made concerning what "will" be done by ERDA to satisfy the national "oughts" specified in the normative planning phase through the "hows" described in the strategic planning phase. The key outputs of this phase are technology program plans (e.g., fossil, geothermal) that set forth in detail what will be accomplished; these plans serve as a key input to the resource allocation, program implementation, and program evaluation activities.

Environmental Planning

ERDA recognizes the need to ensure that environmental planning and performance are reviewed at the highest levels of decision-making. Environmental and health goals are addressed at each decision point (i.e., concept, research, pilot plant, demonstration) and related to the technological and economic goals for energy production alternatives. In this way, energy RD&D alternatives are designed to have minimal environmental impacts and energy development decisions can be approached with full cognizance of their environmental implications.

The environmental planning process results in several major outputs: an Environmental Development Plan, a Balanced Program Plan, and an Assessment of Environmental Impacts. The keystone of the process is the **Environmental Development Plan** (EDP), which is prepared to accompany the program plan for each major technology thrust. The program plan and the EDP for a given technology guide the research that ERDA must coordinate to ensure that the technology is environmentally acceptable. The purpose of the EDP is to ensure consideration of (1) the health, environmental, safety, and control technology requirements that must be met for the technology to become acceptable, and (2) the social and institutional implications of the technology. These issues are often neglected until the technology is well advanced, leading to costly delays at a time when the technology may seem most promising.

The EDP documents the planning, budgeting, management, and review processes for the environmental aspects of each energy technology, and also:

- Assesses the current status of understanding with respect to environmental and institutional problems
- Identifies major problem areas and topics requiring research
- Designates significant milestones
- Specifies requirements for performance monitoring and supporting research.

Definition of the EDP requires close interaction between those responsible for developing the energy technologies and those responsible for ensuring their environmental acceptability. This close coordination will provide the necessary visibility to ensure that all components are compatible.

The **Balanced Program Plan** (BPP)* is, in effect, the program plan for ERDA's environmental research. Environmental research must normally be conducted along disciplinary (as opposed to energy technology) lines. Using the information collected in the EDPs, the BPP defines the disciplinary research that must be performed to meet the needs of all energy technology development.

The remaining component of the environmental planning process is the **Assessment of Environmental Impact**, which culminates in the preparation of environmental impact statements at major decision points in a technology's development. This process provides the primary means for identifying and documenting the environmental, technological, economic, and other factors considered in decision-making. As public communication is an essential part of this process, activities are structured to inform the public and organized interest groups of estimated impacts and to provide open channels for ERDA to respond to specific public concerns in the decision process.

Resource Allocation Activities

Resource allocation activities are based on:

- Federal role and objectives defined through strategic planning
- Relative program priorities and long-term resource requirements based on strategic planning and an estimate of future budget constraints
- Status of the current program (e.g., study phase, pilot operations, demonstration plant) including the work to be done, as described through program planning and the degree of private-sector cost-sharing being achieved
- Size and relative priorities of the Federal budget, as determined by the President and Congress based on total budget constraints and competing demands for Federal funds.

On the basis of this information, trade-offs aimed at allocating ERDA resources to the most important activities can be clearly defined.

* ERDA–116, **Balanced Program Plan Analysis of Biomedical and Environmental Research.**

Program Implementation Activities

Program implementation activities focus on the development of an operating plan that delineates the specific activities to be accomplished within approved budgets. Through program implementation, ERDA management:

- Approves program execution, including annual operating plans for specific programs
- Establishes the controls that govern implementation by the operating elements
- Establishes the milestones or other means for management review considered essential to control the program
- Prescribes the framework for timely reporting against these milestones.

Program Evaluation Activities

The overall PPBR process is dynamic and adaptive. Managerial action is initiated in response to specific problems, defined as an identified difference between an existing situation and a desired situation (e.g., perceived actual progress versus scheduled progress on an RD&D program).

The program evaluation process produces exception reports that identify differences between the desired conditions specified in the operating plan and the current actual conditions. Actions to eliminate or reduce serious differences are then defined. The program evaluation process is conducted monthly.

Annually, a summary review is conducted to evaluate program progress vis-a-vis program objectives and approved milestones specified in the operation plan. In addition, in-depth evaluation of selected key programs are conducted each year, with all major programs receiving an in-depth review every three to four years. Program evaluation feeds back to program design and resource allocation decisions.

PPBR System Outputs

The PPBR system generates seven key documents, the first of which is the **National Plan for Energy RD&D.** The Plan documents the normative planning work performed by ERDA. For example, Chapter II summarizes the goals and priorities that help define what ought to be done if the energy problem is to be resolved through technology development, and Chapter VI describes some of the initial analytical work undertaken to support normative planning.

The **ERDA Budget** is the other important comprehensive document. The budget presents near-term priorities and the annual allocation of resources.

The five remaining documents are developed for each technology program:

- **Program Strategy.** This document explores the need for a Federal role and the effectiveness of RD&D and other programmatic solutions. A program strategy for the market penetration of energy systems options is presented, and the major goals and milestones for programs necessary to implement that strategy are established.
- **Program Plan.** The program plan charts the detailed course of the program over a period of several years, including major programmatic decisions (e.g., should a demonstration phase be undertaken?).

  The plan specifies elements such as management structure and roles of other agencies, and definies the most cost-effective Federal program for achieving the agreed-upon objectives.
- **Environmental Development Plan** (EDP). A companion document to the program plan, the EDP outlines the program of environmental research that must parallel technology development, and details a program for resolving those issues in a time period consistent with the rate of technology RD&D.
- **Program Approval Document.** The PAD is a primarily internal ERDA document that functions as an operation plan. A one-year slice of the program plan, the PAD's purpose is to provide a baseline for monitoring program operations during a given fiscal year. The PAD also contains some summary program plan material to provide a context for fiscal year operations.
- **Environmental Impact Statement** (EIS). Within the structure of the National Environmental Policy Act, ERDA intends to use the EIS as a major input to decision processes. Where required, an EIS describing major program decisions is prepared. The EIS contains a summary of the information developed by the EDP and addresses environmental and other issues raised in the EDP. In tihs way, environmental issues are identified at the beginning of an appropriate program phase and systematically addressed throughout the planning process.

A variety of analyses link the National Plan and the individual program planning documents. Economic considerations, for example, help establish the relative costs and benefits of technological change. Net energy analyses, energy system studies, and energy-environmental trade-off studies help distinguish the relative priorities of discrete technologies within a class of technologies. The status of ERDA's ongoing efforts in the areas is discussed in Chapter VI of this report.

ERDA believes that its overall planning process will benefit from comment and consultation by others. To facilitate this interchange, the key steps in ERDA's planning must be understood. Accordingly, ERDA intends to publish descriptions of its PPBR system as they become available.

DEVELOPING THE PLAN

Chapter VI—Factors Influencing the Evolution of the Plan

The National Energy RD&D Plan must be responsive to continuous changes in the world, both with regard to energy and non-energy events and policies. For example, changes in private investment and technology development, in oil and gas reserves, in energy demand levels, in economic conditions, in environmental considerations, and in life styles affect the basis on which the Plan is drawn.

In arriving at this revision of the Plan, ERDA has examined a number of factors, falling into three principal areas:

- An assessment of the basis on which the earlier version of the Plan was predicated, including: domestic and world energy resources; and energy, economic, environmental, legislative, and other developments.
- An assessment of the comments and criticisms of ERDA-48 by: industry; the general public; regional, state, and local interests; other Federal agencies; and Congress. These useful comments have materially influenced the Plan.
- An assessment of recent energy system analysis studies aimed at: understanding the relationships between energy, economic growth, and environmental impact as a result of the introduction of new energy technologies and other energy policy initiatives; calculating the net energy aspects of energy technologies; and supporting market penetration initiatives through specific market studies. Although most of these studies have not yet been completed, it appears that they will be extremely useful in: selecting the most promising from among the large number of individual energy technologies being proposed; and materially assisting in clarifying the degree of Federal participation, if any, required to develop and introduce new technologies. They do not yet suggest the need for a sharp revision in the basic goals and strategies of this Plan.

Subsequent sections of this chapter review each of the above assessments, and describe their implications for this Plan. In future Plan revisions, ERDA will continue to make and report on similar assessments.

International and Domestic Events

The fundamental strategy of this Plan is to broaden the domestic energy resource base through the introduction of new energy technologies in the private sector. This strategy is based on the observations that worldwide supplies of oil and gas are finite, that domestic production of oil and gas has entered a stable or declining phase, and that other domestic energy resources are available in significant quantities. Events of the past six months, which are reviewed below, support this appraisal. Moreover, clarification of U.S. energy policy by the President and Congress, although very important for the near term, does not alter the fundamental problem of imbalance in the Nation's use of energy resources.

Geographical Concentration of World Energy Resources and Reserves

Although world energy fossil fuel reserves are very large, their geographical concentration is an important consideration in assessing availability. Petroleum and natural gas reserves are largely concentrated in the Eastern Hemisphere, with over half of the world's total in the Middle East and North Africa, and most of the remainder in the Soviet Union. The U.S. has the next largest reserves of oil and gas. But in spite of the large Canadian and Venezuelan producing industries, the oil and gas reserves of the Western Hemisphere represent only 13 percent of the world total.

Reserves are essentially the proven inventory that producers must have on hand to continue operations. Based on world rates of production in 1974, the total reserves of petroleum would last for another 35 years and the world coal reserves would last for about 175 years. Of course, these global averages are deceiving because not all producers have equal call on the existing stock, and, further, demand can be expected to increase in the future.

The level of reserves is not static and it is generally expected that additional **resources** will be located and moved into the reserve category in the established producing areas. Resource estimates (usually several times as large as the reserve estimates) include extrapolations not only of additions in existing proven areas, but speculations about potential new discoveries elsewhere. In the Middle East, some estimates suggest that the presently published petroleum reserves may ultimately be at least twice as large. The U.S. Geological Survey estimates that ultimately there may be from two to four times the current demonstrated U.S. reserves of liquid fuels. Even more speculative, but of great current interest, is the growing potential of offshore production of oil and gas, particularly in the U.S., the North Sea, and the Canadian offshore (including the Arctic).

Unless properly interpreted, however, data on resource estimates can be misleading. These resources are not ensured sources of supply, since in many cases, technological advances are required to locate, develop, and use them in economically and environmentally acceptable ways. Appendix A provides a more detailed discussion of the world energy resource picture, including data on the geographical concentration of reserves and on the magnitude of total reserves and resources.

It seems reasonable to conclude that the geographical distribution of fossil energy resources will not be radically different from the distribution of today's reserves. In this regard, the U.S. has about 8 percent of the world's recoverable oil and gas reserves and about 35 percent of the recoverable coal reserves. Discovery of new reserves can stretch the world's finite fossile resources, and that is desirable; but, new discoveries are unlikely to result in changes in the location of new reserves. To the extent that a nation wishes to draw on domestic energy resources, the long-term problem remains.

Continuing Worldwide Dependence on Oil and Gas

In spite of rising costs, the worldwide trend toward greater dependence on oil and gas has continued since the original National Plan. This trend is expected to continue unless affirmative action is taken to increase the use of coal and develop alternative sources.

Developed countries, other than the centrally planned (Communist) economies, and the less developed countries rely on gas and oil, particularly imported oil, for three-fourths of their energy needs. Reliance on coal is minimal in the less developed regions, except in a few countries such as India and Korea. The centrally planned economies, however, rely on coal for over half of their total energy supply and on oil and gas for most of the remainder.

In many countries, there are few alternatives to imported oil. The prospects for coal are not encouraging in some countries. Price incentives and advantages will continue to favor rapid development of oil and gas until new energy sources are available. The less developed countries would benefit greatly from new technologies to use solar and other renewable resources. Developed countries can undoubtedly be of assistance in transferring and applying such technologies.

Thus, the inertia of an infrastructure devoted to oil and gas, the difficulty of converting . . other resource bases, and the absence of alternative domestic energy resources in some countries (e.g., Japan) will all contribute to a continuing or increased worldwide dependence on oil and gas. Short-term variations in petroleum supplies should not obscure the fact that in the long run a finite resource will, in the absence of action to the contrary, be subjected to increasing demand.

Continuing U.S. Dependence on Oil and Gas

The problem of continued heavy reliance on the least abundant resources remains. The current reliance on oil and gas in the U.S. is reflected in recent statistics on energy consumption. As shown in Table VI-1, these two sources accounted for approximately 75 percent of total consumption in 1974. Based on early estimates, these fuels accounted for about the same percentage of total consumption in 1975.

Dependence on imported oil has not decreased significantly even though U.S. oil demand has remained well below the level of just two years ago. The decline in energy demand in the U.S. has been about 2 percent in each of the last two years, while the level of imported petroleum has also fallen slightly and is not greatly below the level of 1973. In spite of increased OPEC prices, the import dependence on OPEC countries in general and the Arab countries in particular has grown during the past year. Imports now account for about 37 percent of total oil consumption, with OPEC countries accounting for about two-thirds of all imports.

The normal economic expectations that higher prices would bring forth marginal supply and add diversity among export sources have not materialized, at least in the short term. Recent increases in domestic drilling and exploration activity should, however, lead to new fields and additional production in the future.

Import dependence on OPEC production is not likely to decline in the near term. Western Hemisphere sources have not proven reliable offsets to Middle East and other Eastern Hemisphere production. Canadian crude oil exports to the U.S. are scheduled to be cut by one-third in 1976 as compared to 1975, and to be phased out entirely in 1981. Venezuela, which had long been regarded as a favor-

Table VI–1 U.S. Gross Consumption of Energy (10^{15} BTU)*

	1974							Estimated for 1975	
Energy Source	Household and Commercial	Industrial	Transportation	Utility Electricity Generation	Misc.	Total Energy Inputs	Percentage of Total	Total Energy Inputs	Percentage of Total
Coal	0.314	4.406	0.002	8.520	—	13.241	18.2%	13.394	18.8%
Natural Gas (Dry)	7.518	10.018	0.685	3.512	—	21.733	29.8%	20.173	28.4%
Petroleum**	6.061	5.907	17.720	3.480	0.246	33.414	45.8%	32.701	46.0%
Hydropower	—	0.037	—	3.253	—	3.290	4.5%	3.158	4.4%
Nuclear Power	—	—	—	1.202	—	1.202	1.6%	1.652	2.3%
TOTAL	13.893	20.368	18.407	19.967	0.246	72.880	100.0%	71.078	100.0%

Source: U.S. Bureau of Mines

* Data may not add to total because of independent rounding.
** Including natural gas liquids and refinery gases.

able source of oil supplies for the U.S., plans to hold its long-term production to about 2 million barrels per day although its current daily producing capacity is in excess of 3 million barrels. Other Western Hemisphere sources have little export potential and the U.S. expects no sizable additions to domestic production until North Slope oil starts to flow in 1977. Consequently, U.S. dependence on the Middle East and other Eastern Hemisphere sources may increase even more in the near term.

In the near term, it is physically possible for foreign sources to supply our needs. Spare producing capacity in OPEC countries was recently estimated at 10 million barrels per day. OPEC production had fallen from a quarterly peak of 32 million barrels per day prior to the Arab oil embargo to a low of 26 million barrels per day in the spring of 1975. Higher levels of production and exports in the third quarter, prior to the October 1 increase in OPEC prices, were followed by sharp cutbacks after the 10 percent increase took effect. At the same time, with economic recovery under way in the major importing countries, it is likely that energy demand will increase and the decline in OPEC production will be halted.

As economic and energy growth resumes in the U.S., there is a danger of slipping back into the same pattern of meeting incremental supply needs with imported oil. The current upturn of economic activity in the face of declining domestic oil and gas production will probably lead to higher imports initially. Domestic crude oil production was at a rate of 8.4 million barrels per day in 1975—more than a 10 percent decline from the level prior to the embargo in 1972. Domestic production of natural gas peaked in 1973 at 22.6 trillion cubic feet; in 1975, production was around 20 trillion cubic feet.

National determination to conserve in energy use, to develop new sources of energy supply, and to shift demand from oil and gas to more abundant energy forms will be tested as economic growth resumes. A measure of this difficulty is available from the recent experience during the recession, when the decline in total energy use was comparable to the decline in economic activity. It appears that in addition to a general slowdown in economic growth, conservation also contributed to the decline in energy use. FEA has estimated that, in 1975, 3 million barrels of oil per day less were consumed as compared to historic expected projections of demand, and that conservation efforts accounted for a substantial portion of the reduction. Yet the proportion of imported oil changed very little.

The short-term reliance on oil and gas is compounded by the obstacles to using those resources which could be expended relatively quickly—coal and nuclear power. Technical, environmental, and institutional factors come together to inhibit increased utilization of these resources. The prospect of increased reliance on imported energy to meet domestic energy needs argues strongly for technology developments in general, and for near-term conservation and fuel substitution initiative in particular. In addition, it is important that the efforts of individual nations be coordinated through mutually reinforcing international cooperative programs, as discussed in Chapter IV.

New Assessments of Domestic Resources

The U.S. has both the domestic resources and the technical capability to provide alternatives to oil and gas. Periodic assessments have indicated the extent of these resources. Resource assessments in the U.S. are much more thorough and soundly based than in most of the rest of the world. The frequency of resource surveys, formalized documentation procedures, and the use of high-technology exploration equipment all enhance the reliability of the resource estimates.

Nonetheless, new assessments are made periodically and significant changes in estimates of the resource base do appear. As a result of new assess-

Table VI–2 Recoverable Energy Resources of the United States (In Thermal Equivalents)

Resource	Units	Data in ERDA–48 Report	Data from Recent Official Reports			
			Demonstrated Reserves	Additional Resources	Total	Source and Explanation
Coal	Quads	12,000	4,900	16,500	21,400	ERDA–48 excluded hypothetical resources and those in areas likely to be closed to mining
Natural Gas	Quads	775*	244	706	950	Estimates based on "Mean Values" of USGS range of undiscovered resources
Petroleum**	Quads	800*	246	704	950	Estimates based on "Mean Values" of USGS range of undiscovered resources
Shale Oil	Quads	1,200	727	473	1,200	Western and Alaskan shales yielding 25–100 gal/ton
Uranium***	Quads	1,800	900	900	1,800	Utilized in LWRs
Geothermal	Quads	400	102	3,332	3,434	Recoverable heat with present or near-term technology

* ERDA–48 data based on the USGS "High Probability" estimates but excluding resources that may be produced through techniques to enhance recovery rates.
** Crude oil and natural gas liquids.
*** The use of uranium in breeder reactors could expand the resource base to about 130,000 quads.
Note: See discussions in text and bibliography for detailed references.

ments reported since ERDA-48, the estimated domestic resource base has risen significantly for coal and more thorough appraisals have been made of geothermal and other resources. **These new assessments are primarily the result of different interpetations of previously presented data and, in the case of coal, of major additions to the more speculative resources. Nonetheless, they tend to confirm the belief that the U.S. has significant domestic energy resources that could be used to reduce dependence on oil and gas.** Table VI-2 shows the new estimates as compared to those in ERDA-48.

In a new U.S. Geological Survey study,* the total coal resource base was increased 25 percent from 3.2 trillion short tons to nearly 4.0 trillion short tons. The bulk of the increase was in hypothetical resources (587 billion tons), while identified resources were increased by 11 percent (171 billion tons). Coal resources currently considered recoverable account for less than one-third of the nearly 4 trillion tons, reflecting quantities in seams too thin to be mined economically and providing for a recovery rate of 50 percent. Hypothetical resources and those in areas likely to be closed to mining operations were not included in the ERDA-48 analysis.

Since the U.S. Geological Survey had completed a new study** of oil and natural gas resources prior to the preparation of ERDA–48, it was possible to use these new USGS estimates in that analysis. A follow-on study planned for completion in mid-1976 will reappraise oil and gas estimates in light of the recent changes in price-cost relationships that were not taken into account in the 1975 study. These important price effects could change the outlook in several ways: (1) some resources formerly uneconomic to recover may now be recovered, (2) the percentage rates of recovery may improve, and (3) reserves may be produced at a more rapid rate.

The rate at which the existing and newly established reserves of oil and gas will be produced is the most crucial short-term variable. If producers' prices are high and expectations for further price increases are lessened, there could be a strong incentive to deplete reserves much more quickly than previously estimated. However, unless the basic resource estimates are in error, the result may be simply to ease the short- and mid-term problems and aggravate the problem in the long term. Expanding the application of enhanced oil and gas recovery techniques is a key program initiative for achieving the goals of the National Plan for Energy RD&D. These aspects of this initiative were discussed in greater detail in Chapter III.

An extensive evaluation of uranium resources is now under way that will be based on detailed nationwide geological, geophysical, and geochemical studies and surveys. The evaluation will take several years to complete, but information will be made available as it accumulates. A preliminary report published in January 1976 indicated a 50 percent in-

* USGS Bulletin 1413 (Averitt), "Coal Resources of the United States, January 1, 1974," Washington, GPO, 1975.
** USGS Bulletin 725 (Miller et al.), "Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States," 1975.

crease over earlier estimates, but the ERDA-48 analysis had been based on the later estimates, which were then unpublished.

A new assessment of geothermal resources was recently completed by the USGS in cooperation with ERDA.* For each identified geothermal system, the parameters used in calculating volumes, heat content, and recoverabilities are listed. The preliminary estimates disregard costs, and they will be revised as more data and better methods of evaluation become available. The geothermal potential that will eventually be realized is dependent upon the development of new technologies for exploiting the various systems in economic and environmentally acceptable ways. Estimates of the total potential would vary with the combination of resource systems employed and with variations in the technologies to be used and the rate of exploitation within each of the four major categories. For example, the estimates for hot dry rock and magma are based on assumptions of relatively low heat extraction and conversion efficiencies. Higher efficiency assumptions would increase these several times. The estimated resources are shown in Table VI-3, on a heat equivalent basis.

In the long term, thorium resources could also be important, but they do not seem likely to represent a significant alternative energy source in the near term. Thorium is a relatively abundant element (6 parts per million in the earth's crust vs. 2 parts per million for uranium), and resources are more than adequate to meet any foreseeable needs. No new estimates of thorium have been prepared in recent years.

Table VI–3 Geothermal Resources—Estimated Recoverable Heat with Present or Near-Term Technology
(In Quads)

Resource Type	Known	Inferred	Total
Hydrothermal Convection			
Vapor Dominated (>150 degrees C)	2	2	4
Liquid Dominated			
High Temp. (>150 degrees C)	20	110	130
Low Temp. (90-150 degrees C)	80	250	330
Geopressured			
Electrical Utilization	100	230	330
Methane Production	50	1,500	2,000
Hot Dry Rock	80	240	320
Magma	80	240	320
Total	362	2,572	3,434

NOTE: Does not include (1) normal gradients of heat in the earth, or (2) hydrothermal convection systems less than 90 degrees C.

Source: Definition Report: Geothermal Energy Research, Development and Demonstration Program (ERDA–86), October 1975, pp. 1–7.

Other Events and Developments

There are many legislative and environmental developments which potentially will affect the National Plan and program implementation. Recent legislative initiatives address automotive, consumer, and industrial conservation; the development of fuel supplies from lands subject to federally controlled mineral rights; strategic storage of petroleum fuels; changes in the pricing structure for oil; and Federal encouragement of new technologies. Environmental initiatives, particularly at the state and local level, must be taken into account in fostering the development of nuclear power and the extraction of fossil fuels.

The Energy Policy and Conservation Act,** recently signed and passed into law, has major implications for the Plan. This is especially true in the conservation area, as discussed in Chapter III. In general, the Act stresses conservation and the use of coal—policies which are entirely consistent with the Plan.

The legislation also establishes a framework for the gradual, but complete, removal of oil price controls. This partial resolution of uncertainties concerning price should allow the private sector to plan more meaningfully for additional domestic energy production. The exploration for and development of not only petroleum but all competing energy sources can proceed more smoothly, including the enhanced oil and gas recovery and synfuel initiatives discussed earlier.

Other developments have more effect on broad aspects of energy policy. These developments are important, nonetheless, to the extent that they influence the choice of new energy technology options at some future time period. Expanded oil and gas supplies from areas where the mineral rights are controlled by the Federal Government and the proposed deregulation of natural gas are examples.

Environmental developments are critical to the evolving Plan. Several current environmental initiatives are generic in nature (e.g., nondegradation legislation, state implementation plans for meeting national ambient air quality standards), with potential effects on all energy implementation plans. Other initiatives are program-specific (e.g., water rights for use in coal slurry pipelines, statewide moratoria on new nuclear power plants).

The implications of these developments on the Plan relate primarily to the need to identify the major environmental and other issues in the context of specific programs, and to incorporate the resolution of these technical and non-technical issues into technology development plans. This implies a strong requirement for inter-agency cooperation (discussed in Chapter IV) as environmental standards and techni-

* USGS Circular 726 (White and Williams), "Assessment of Geothermal Resources of the United States—1975," 1975.

** Public Law 94–163

cal RD&D programs are modified to meet changing requirements.

Assessment of the Plan by Others

The importance of the review of the National Plan by others is expressed in Congressional requirements. In 1975 Congress requested the Office of Technology Assessment to conduct a formal review of the National Plan.* Also, The Non-Nuclear Energy Research and Development Act directs the Council on Environmental Quality to undertake an ongoing assessment of the adequacy of attention to environmental protection and energy conservation in the energy R&D programs. In conducting this assessment CEQ is to hold annual public hearings, which in 1975 focused on a number of aspects of the National Plan.** In addition, the external review of the Plan includes the solicitation of comments from state and regional energy representatives, public and special interest groups, industry, the general public, and other government agencies. This section summarizes the most important comments and discusses how they influenced the Plan. Other government agencies provided initial input to the first National Plan in the area of program implementation. (Summaries of their energy RD&D programs were contained in Volume 2 of ERDA-48.) In the current Plan, other agency input and review to Volume 1 (The Plan) and Volume 2 (Program Implementation) were solicited.

Review by OTA and Public Hearings Held by CEQ

The OTA review and CEQ hearings on the National Plan for Energy RD&D produced the most comprehensive and wide ranging comments on the Plan. In general, the review and comments were most useful in highlighting those areas where the Plan could be made more responsive to the energy problems facing the country. The comments can be grouped according to three primary issues:

- **The basis for planning and program execution and the resulting priorities should be reexamined.** Criticisms included: excessive reliance on a hardware-oriented approach; inadequate emphasis on conservation; too little attention to nontechnical impacts resulting from technology development; too little focus on near-term energy problems; imbalance between energy supply and demand RD&D; overemphasis on high technology, capital-intensive energy supply alternatives such as electrification; inadequate emphasis on solar energy; inadequate emphasis on commercialization; lack of established goals for the basic research program; lack of importance given to environmental control and protection; and management policies that appear inadequate to achieve goals.
- **The degree of cooperation and coordination with others should be increased.** Criticisms included: insufficient provision for coordination and cooperation with international concerns, Federal agencies, state and local governments, and the general public in energy planning and policy making.
- **The analysis supporting the Plan should be more comprehensive.** Shortcomings were noted in: economic and socioeconomic analysis; cost/benefit analysis; resource assessment; foreign policy options; physical, environmental, institutional, and social constraint analysis; and net energy analysis.

The current Plan reflects the OTA comments and criticisms, and comments expressed to CEQ at its hearings, particularly in the sections dealing with near-term initiatives; the conservation program priority; major environmental issues; increased coordination with others; analysis of energy and economic relationships, including constraint and net energy analysis; and the role of basic research. However, many of the issues raised are complex, and have not been resolved in this document. ERDA will continue to incorporate these comments in future revisions of the Plan.

Other comments obtained from the OTA review and the CEQ public hearings indicated that the Federal mission, as expressed in the goals of the Plan, was too narrow. A related issue was the need for an expanded national energy RD&D program reflecting circumstances following the Arab oil embargo. A significantly higher budget was suggested to accommodate the adoption of a broader mission and the urgent need for energy solutions. These issues were underscored in the OTA review:

> ERDA's Plan in many instances acknowledges the need for such a broad perspective and program. In fact, the problems are not so much within the Plan itself—which is a serious and praiseworthy initial effort—but in the lack of a broad commitment and coordination when the Plan, Program and Budget are considered together.***

Chapter III summarized the ERDA portion of the national energy RD&D budget and program implementation. The funding levels in this program implementation plan reflect the Administration and Congressional assessments of the current energy situation subject to the effective utilization of manpower, facility, and budget resources.

Certain issues highlighted in the OTA review and CEQ hearings (e.g., the desirability of greater

* United States Congress, Office of Technology Assessment, **An Analysis of the ERDA Plan and Program**, October 1975.

** Council on Environmental Quality, **Summary Report on 1975 Public Hearings:** Environmental Effects and Energy Conservation Aspects of the Nonnuclear Energy RD&D Programs, January 1976.

*** United States Congress, Office of Technology Assessment, **An Analysis of the ERDA Plan and Program**, October 1975, p. 4.

energy independence as an energy policy goal) require broad public policy discussion since they affect large segments of U.S. society. Decisions on these issues cannot be made singularly by government agencies or by narrow segments of society. The Plan can, however, help focus on these issues by providing supporting analysis and forums for discussion. For example, preliminary conclusions regarding the impact of energy policy on other sectors of the economy are presented later in this chapter in a separate discussion on energy systems analysis studies.

ERDA Regional Public Review

The public review of the Plan provided important insights into specific regional energy issues. In the two public meetings that were held,* regional concerns were expressed about the future potential of various energy sources. These comments reflected the uniqueness of regional environments and were tied to local perceptions of the nature and importance of problems associated with development of energy alternatives.

The other main issues addressed by the participants in the public metings were:

- The goals of the Plan should be more realistic and should consider such regional constraints as resources, capital, and manpower.
- The degree of coordination between the Federal Government and state, local, and regional concerns should be improved to ensure successful and acceptable energy policies and programs.
- Criteria for ranking technology priorities should consider the impact of technology development on economic, environmental, social, and political systems. The budget should reflect these priorities.
- The nuclear alternative should be assessed more carefully in terms of environment, health, and safety.
- Government incentives should be available to ensure commercialization of new technologies.
- Conflicts of water use between energy and nonenergy uses should be resolved.
- In view of finite resources, an ever-increasing rate of energy growth should not be encouraged.
- Economic and net energy analyses should be used in assessing alternative energy sources and technologies.
- The importance of short-term energy planning should be emphasized. Conservation and other alternatives such as solar, geothermal, biomass conversion, and hydrogen should receive higher priorities.

Another form of public review was provided by interaction between industrial representatives, trade associations, state energy offices, public interest groups, and Federal program planners. These groups were asked (by letter from ERDA**) to provide their views on energy RD&D. As a result of this solicitation and the regional review process, ERDA program managers and their staffs met with representatives from industry, public interest groups, and state and regional energy groups.

The comments elicited from the public review process have been carefully examined and evaluated. **These comments have helped shape the current National Plan, most notably in the areas of program priorities (e.g., the new emphasis on conservation) and coordinating activities with state, regional, and local groups (e.g., the emphasis on establishing a national energy organizational infrastructure).** In addition, energy analysis conducted at the state and regional level will be useful in focusing the energy systems analysis efforts which influence the Plan.

Energy Systems Analysis Studies

Subsequent to the development of ERDA-48, several studies were undertaken to address issues raised by the Plan and related comments. For example, it was clear that more analysis of economic effects, and energy-environmental trade-offs was required. Similarly, ERDA believed that the cumulative impact of technology change in the utility industry deserved more study, as did the situation posed by other countries that sustained a high economic growth with relatively low energy consumption.

These studies are nearing completion, will be published for external review and comment, and are expected to provide important insights for future planning. At this point, the study results are preliminary, but appear consistent with the Plan. Specifically:

- The new emphasis on conservation and the reliance on technological solutions to achieving energy goals are reinforced by results obtained from a study of the **relationship between energy and economic growth.**
- The choice of energy RD&D technologies is reinforced by a study which indicates that, of the technologies investigated to date, all are supportable on the basis of a **net energy analysis.**
- The difficulty of quickly changing the Nation's consumption patterns to show improved energy-economic efficiency is highlighted in a study of **foreign energy consumption patterns.**
- Finally, the importance of emphasizing the coal and light water reactor nuclear initiatives, discussed earlier in Chapters II and III, is highlighted in a **market study of the electric utility industry.**

* The first meeting was held in Atlanta (October 1975) and the second in Seattle (December 1975). The Bibliography lists the publications for these meetings.

** Via letters from the Assistant Administrator for Planning and Analysis to representatives of these groups in March and July 1975.

In addition to the four study areas above, the conceptualization of energy, economic, and environmental trade-off analysis and the analysis of economic constraints to energy growth are being investigated.

The study of energy systems is dynamic. As more is learned about the role of energy in society, both the problems being addressed and the tools and techniques of analysis are subject to change. This section presents selected preliminary results and conclusions from ongoing energy systems studies.

The purpose of the analysis, highlights of emerging conclusions, and references to existing and planned detailed reports are presented for the energy studies.

Each study is summarized in the balance of this section. The conclusions and results are based on a series of independent analyses. The supporting studies are only indirectly related to each other, primarily through the common input assumptions related to possible energy futures (i.e., the ERDA–48 scenarios). New and continuing studies are, however, a key ingredient of the ERDA planning system, as discussed previously in Chapter V.

Relationship Between Energy and Economic Growth

The effects of alternative future energy scenarios on the U.S. economic system must be better understood. This need is underscored by concerns over the impact of rising energy prices on overall economic growth, energy demand, inflation, and employment. Other areas of interest include the impact of new technology introduction on the economic system and on the cost of providing energy.

The relationship between energy and economic growth are complex but must be addressed to ensure the compatibility of energy policy goals with other societal goals. Accordingly, the main purposes of analysis efforts in this area are to:

- Develop methods for measuring the interrelationships between energy production and consumption and economic growth. The interrelationships include those among: energy demands, prices, and income; energy supplies, prices, and domestic economic output; and energy RD&D impacts, inflation, labor requirements, and capital requirements.
- Provide information on the economic impacts of energy technology introduction. Impacts such as changes in material, labor and capital requirements, aggregate GNP and its distribution to consumption, investment, and foreign trade are important to permit evaluation of alternative energy policies.
- Differentiate between the energy-economic effects of energy RD&D policies and those of other policies. For example, it is important to provide information on the effects associated with policies aimed at increasing energy supplies (such as through expenditures on new technologies) as compared to those associated with policies aimed at curtailing demand (such as demand reductions through price increases).

New technologies designed to exploit the Nation's abundant domestic resource base are expected to be available at different times and in varying quantities over the next two decades. Contributions to energy supplies are expected from oil shale, coal liquefaction and gasification, geothermal energy, and solar electric and direct solar applications. To the extent that these technologies can compete with existing energy sources, including imports, they can reduce the Nation's dependence on foreign energy supplies. Therefore, one strategy for meeting the Nation's energy policy goals relies on increased domestic supplies. Another strategy involves reductions in energy consumption.

Four models were utilized to describe the interreactions existing between factors of energy supply and demand and economic activity. These models, discussed at the end of this section, were used to test alternative supply and demand policies against a base or reference case. This case assumed the continuance of present economic and energy practices and conditions; the only exception was the assumed decontrol of oil and gas prices.* The alternative policies were evaluated in terms of their effects on economic growth and on the achievement of prespecified import targets. These policies were based on the following:

- A supply policy was based on the introduction of the new technologies mentioned above. The estimates of the maximum energy flows that could be expected from the new technologies were based on the technical calculations (scenarios) contained in ERDA-48. Import target levels were set as a declining percentage of total domestic energy use.
- A demand policy was based on rising energy prices (via taxes and tariffs only). Demand measures (rising energy prices) were used to eliminate any supply/demand gap still remaining after the introduction of new technologies. The procedure used was to increase the prices of energy supplies grad-

* During the conduct of these evaluations, ERDA and FEA collaborated closely on the energy projections generated by FEA through its Project Independence Evaluation System (PIES) model. ERDA believes that the FEA modeling efforts provide a very logical and detailed approach to evaluating economic interactions for the 1975–1985 time frames. Thus, ERDA has chosen not to duplicate these efforts, preferring instead to work with FEA to produce a mutually agreed upon set of projections for the next decade. Conversely, ERDA has taken the lead role for examining the energy-economic interactions for the 1985–2000 time frame, with FEA providing advice and review. The evaluations in this section cover only the 1985–2000 period and were closely calibrated to the FEA results for 1985 to provide the initial point of departure.

ually (which resulted in lower demands) until the specified import target levels were reached. The 1985 import target level was 10 percent of total energy consumption and the 2000 target level was 5 percent.

The preliminary results obtained to date relative to the base case have some important implications for research and development activities and for the implementation of new technology in the market place:

- **The introduction of new energy-producing technology has a significant positive effect on the level of GNP and on the economic well-being of the country.** The discounted value of future GNP restored by adding to supplies (through technology introduction), instead of increasing prices to reduce demand, is several-fold larger than the discounted value of accumulated expenditures on RD&D.
- **Higher prices (30 percent above those otherwise expected in 2000) could be required to achieve the specified energy demand reductions, and this appears to be an undesirable cost to the Nation.** Implementation of more efficient energy using and producing devices would be the preferable way to achieve the import reduction. The price increases needed to achieve a sufficient demand reduction are half as large when new supply technology is available as when it is not available. Energy demands are rather inelastic, with a 10 percent increase in price required to produce a 2.5 percent demand reduction in 1985 and a 4.5 percent demand reduction in 2000.
- **Increases in the inflation rate occur as a result of energy price changes.** In addition to the introduction of new technology, high taxes and tariffs (over 150 percent on oil and 20 percent on gas) are required to achieve the specified lower demands; this leads to a long-term increase in the general inflation rate of about 0.3 percentage point.
- **The effects of higher prices and new technology result in a slowing of the rate of increase in the output of the domestic economy.** The rate of increase in real GNP declines, resulting in a small drop in the level of real GNP (about 2 percent lower in 1990 and 3 percent lower in 2000).
- **Changes in labor requirements result in an increase in unemployment.** A lower real GNP produces a lower demand for labor inputs to the economy. The restructuring of the economy to reduce energy use offsets this somewhat through increased demands for labor as a substitute for energy inputs. The overall result is a long-term increase in the unemployment rate (for both policy alternatives) of from one-half to one percentage point higher than for the base case.
- **New technologies are only marginally competitive with existing technology in the short-run but compete successfully by the end of the century.** New technologies (primarily oil shale, geothermal, and direct solar) may account for 16 percent of total energy in 2000 as compared to only 4 percent in 1985.
- **There is an improvement in energy-economic efficiency (as measured by the energy/GNP ratio).** Preliminary results indicate a 2 to 3 percentage point improvement for each 10 percent change in energy prices.

The set of analytical tools applied to these problems represents an advancement in the state-of-the-art for models of this type. It is the first time a macroeconomic growth model has been linked to an inter-industry sectoral model* and subsequently linked to an energy technology oriented resource allocation model.** These efforts are being jointly pursued through contracts with ERDA.*** It also represents the first time that changes in energy technologies and patterns were introduced into the economic models to determine the new configuration of economic activity and indicators. The relationship among the separate models is expressed in the logic diagram shown in Figure VI-1. Each of the four models have been previously examined and critiqued. Certain adjustments have been made to develop compatible definitions of parameters. The initial results of this ongoing study are to be published by Brookhaven National Laboratory and Data Resources, Incorporated, and will be disseminated for review and comment at approximately the same time that this Plan is published.

These efforts are an integral part of the planning, program, and budget review process now being structured within ERDA. The treatment of other areas of energy-economic analysis—sectoral elasticities, regional considerations, and the sensitivities of individual technologies—has yet to be worked out. Other policy variations (e.g., non-price induced conservation) will be investigated. Additional results and studies will be forthcoming as they are completed.

Net Energy Analysis: The Energy Required to Produce, Distribute, and Conserve Energy

Net energy analysis is the term commonly used to signify the energy expenditures required to pro-

* For additional details see "U.S. Energy Policy and Economic Growth, 1975–2000," Edward A. Hudson and Dale W. Jorgenson, **The Bell Journal of Economics and Management Science**, Volume 5, Number 2, Autumn 1974, pp. 461–514.

** For additional details see "A Methodology of Technical Analysis with Application to Energy Assessment," K. C. Hoffman, ASME Paper 75-WA/TS-8, American Society of Mechanical Engineers, New York, 1975.

*** With Data Resources, Incorporated (macroeconomic and inter-industry sectoral models) and Brookhaven National Laboratory (input-output and resource allocation models).

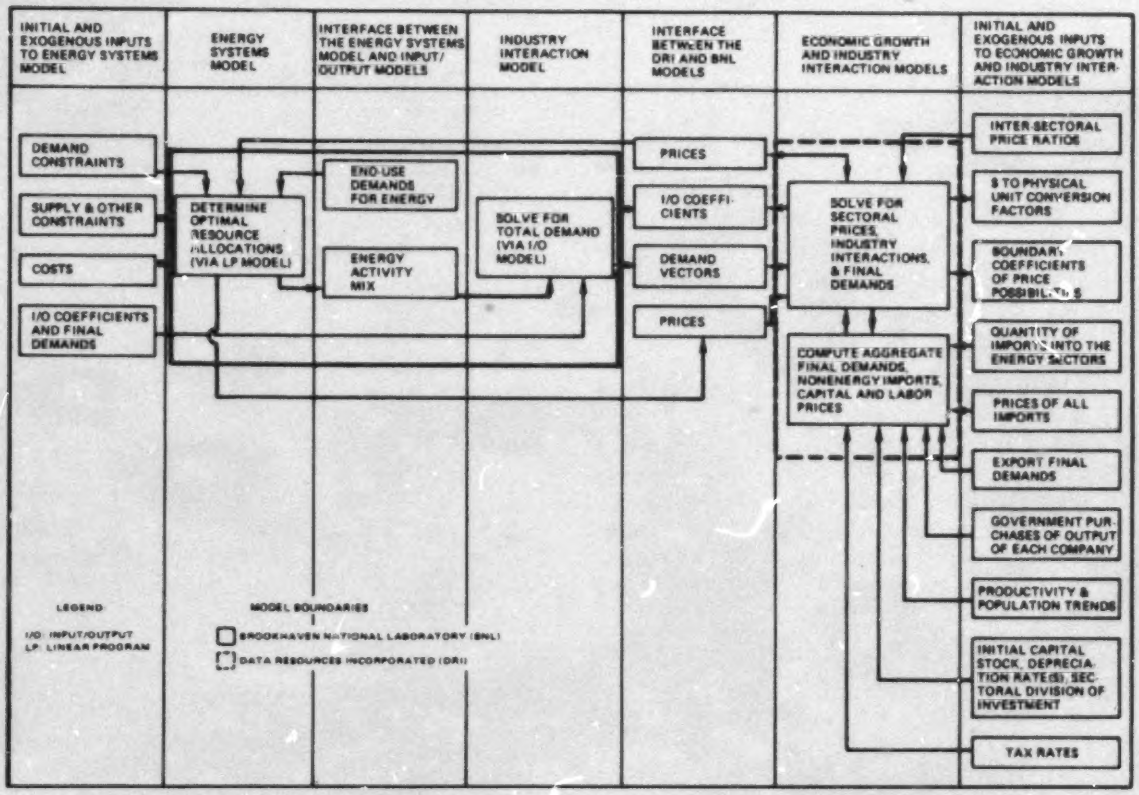

INITIAL AND EXOGENOUS INPUTS TO ENERGY SYSTEMS MODEL
ENERGY SYSTEMS MODEL
INTERFACE BETWEEN THE ENERGY SYSTEMS MODEL AND INPUT/OUTPUT MODELS
INDUSTRY INTERACTION MODEL
INTERFACE BETWEEN THE DRI AND BNL MODELS
ECONOMIC GROWTH AND INDUSTRY INTERACTION MODELS
INITIAL AND EXOGENOUS INPUTS TO ECONOMIC GROWTH AND INDUSTRY INTERACTION MODELS
DEMAND CONSTRAINTS
SUPPLY & OTHER CONSTRAINTS
COSTS
I/O COEFFICIENTS AND FINAL DEMANDS
DETERMINE OPTIMAL RESOURCE ALLOCATIONS (VIA LP MODEL)
END-USE DEMANDS FOR ENERGY
ENERGY ACTIVITY MIX
SOLVE FOR TOTAL DEMAND (VIA I/O MODEL)
PRICES
I/O COEFFICIENTS
DEMAND VECTORS
PRICES
SOLVE FOR SECTORAL PRICES, INDUSTRY INTERACTIONS, & FINAL DEMANDS
COMPUTE AGGREGATE FINAL DEMANDS, NONENERGY IMPORTS, CAPITAL AND LABOR PRICES
INTER-SECTORAL PRICE RATIOS
$ TO PHYSICAL UNIT CONVERSION FACTORS
BOUNDARY COEFFICIENTS OF PRICE POSSIBILITIES
QUANTITY OF IMPORTS INTO THE ENERGY SECTORS
PRICES OF ALL IMPORTS
EXPORT FINAL DEMANDS
GOVERNMENT PURCHASES OF OUTPUT OF EACH COMPANY
PRODUCTIVITY & POPULATION TRENDS
INITIAL CAPITAL STOCK, DEPRECIATION RATE(S), SECTORAL DIVISION OF INVESTMENT
TAX RATES
LEGEND
I/O: INPUT/OUTPUT
LP: LINEAR PROGRAM
MODEL BOUNDARIES
BROOKHAVEN NATIONAL LABORATORY (BNL)
DATA RESOURCES INCORPORATED (DRI)

Figure VI–1 Integration of Economic Growth, Industry Interaction and Energy Systems Models

duce and distribute energy in various forms or to reduce energy consumption in a particular demand process. It is the difference between energy output and the sum of direct and indirect energy inputs. Net energy is a subset of the broader area of energy analysis which seeks to identify and interpret the energy flows in society—both direct and indirect—which are required for the production and distribution of various goods and services. Net energy analysis is an aid to program planning, as it supplements existing economic and technical analysis and provides additional information for evaluating technical programs and project priorities.

Net energy analysis of individual technology options is important for several reasons:

- To determine how much energy must be invested to develop, construct, and operate new technologies
- To supplement economic studies aimed at evaluating the energy resource base and analyzing the cost of new technologies
- To provide a better understanding of the relationships of energy-producing sectors of the economy to each other, to other economic sectors, and to the environment
- To identify significant indirect economic benefits from careful energy management, such as preservation of the environment and conservation of energy resources for future generations.

Net energy analysis is still in an early stage of development and lacks a well-established set of rules and conventions. Substantive questions arise as to:

- Which energy expenditures or resource commitments should be included in the analysis, and what system of measurement should be used
- How energy of different forms (and with different economic values) or energy of like form expended at different times should be aggregated
- Whether a single quantitative value (and if so, which one) can adequately express the significant results of the analysis.

Even if there were no uncertainty in the magnitudes of the various energy inputs, very large apparent discrepancies in reported total energy inputs per unit of net output would still result from different responses to the above questions. These questions can be answered only after additional studies in net energy analysis have been conducted.

Recognizing these difficulties, ERDA used two studies* to prepare conclusions on the net energy of seven basic technologies for producing electricity and nine technologies for producing non-electrical energy. Based on the results to date, the conclusions are as follows:

- **With the exception of very low-grade energy resources, no technologies appear to be "losers" from a net energy standpoint.** These low-grade deposits have not been included in the assessment of the resource base presented earlier.
- **Most technologies return from 4 to 10 times the external energy (i.e., the direct plus indirect energy inputs) expended for energy production.**** That is, the external energy inputs amount to 10-25 percent of the energy output. However, for some conventional fuel supply systems the external energy required is less than 5 percent, while for combinations of processes (e.g., oil from shale used to produce electricity) the requirement can be 40 percent or higher.
- **Nuclear electric power returns about 4 times the external energy required.** A detailed study of the nuclear option is summarized in Appendix B.
- **Net energy analysis is a supplement to, not a replacement for, other more widely used tools of analysis.** Considering the current state-of-the-art, ranking of technologies on the basis of net energy calculations is not as instructive as performing the analysis on specific technologies. The use of questionable assumptions and the lack of comprehensive data preclude extensive reliance on the comparison of results.

Other major technologies will be analyzed and reported on during the year. In addition, future efforts will consider energy demand options and complete supply-to-demand pathways, including the transformation process efficiencies at each step along the pathways.

Foreign Energy Consumption Patterns

Guidance for domestic energy policy will also come from experiences of other nations. Most instructive will be those countries which have achieved a high standard of living with lower rates of per capita energy consumption than those in the U.S. Most notably, several European countries (e.g., Sweden, Denmark, Switzerland, West Germany) have these characteristics.

Studies on foreign energy use and economic growth are needed to:

- Evaluate the level and mix of energy consumption within different sectors and gain understanding of the basic relationship between foreign energy consumption and economic growth
- Identify opportunities for conservation which are applicable to the U.S., and evaluate the extent to which life style changes may be required to achieve lower per capita energy consumption rates
- Form a basis for determining both efficient and wasteful energy consumption practices in the U.S.

Sweden was selected for the first study*** because it has a similar economic performance to the U.S., as measured by per capita gross national product (GNP) and per capita income, and a significantly lower per capita energy consumption rate.

The results of this study plus research by others indicate that major structural changes and efficiency improvements would be required to promote a significant transfer of Swedish energy consumption patterns to the U.S. The major differences are in:

- Makeup of the Economy and Industrial Efficiency: Sweden imports a significant quantity of energy-intensive products (e.g., refined petroleum and agricultural goods), which the U.S. produces internally. The aluminum and petrochemical industries, two important energy-intensive U.S. industries, constitute a smaller proportion of the Swedish industrial mix. On the other hand, Sweden produces significantly higher quantities of paper and pulp than the U.S. and exports large quantities of metal, machinery and transportation equipment. In addition, the energy efficiency of many industrial processes appears to be higher in Sweden than in the U.S.
- Transportation Efficiency: The Swedish automobile fleet, for example, averages over 60 percent better fuel mileage than the U.S. counterpart. Similarly, the Swedish people make greater use of mass transportation.
- Housing Patterns and Efficiency: Swedish homes are much better insulated than in the U.S., resulting in greater efficiency of energy use. Also, little or no air conditioning is required in Sweden. Moreover, one out of five houses in Sweden is heated by hot water distributed from fossil electric power plants; in the U.S., this heat is discharged into the environment and lost.
- Geography and Demography: Urban density is appreciably higher in Sweden and production centers are closer to markets.

* Two studies have dealt with a wide range of energy technologies: "Transition," sponsored by the State of Oregon, Office of Energy Research and Planning, Office of the Governor, 1975; and "A Study to Develop Energy Estimates of Merit for Selected Fuel Technologies," Development Sciences, Inc., September 1975. Originally sponsored by the Department of the Interior, this latter study was subsequently included in ERDA's program. Several other studies are referenced in the Bibliography.

** See Appendix B for a further discussion of the terms used in net energy analysis.

*** A. Doernberg, "Comparative Analysis of Energy Use in Sweden and the United States," Brookhaven National Laboratory, September 1975.

Some changes are under way in the U.S. that promise improvements in per capita energy consumption along the lines suggested by the Swedish experience. For example, efficiency improvements in the U.S. transportation fleet will be forthcoming as a result of the recently signed Energy Policy and Conservation Act. Specifically, auto manufacturers are required to bring their fleet average up to 20 miles per gallon (mpg) by 1980 and 27.5 mpg by 1985. For comparison, the U.S. average of all autos was 13.5 mpg in 1972 while the Swedish average was in the low 20's. In addition to auto efficiency, the Act also provides impetus to future improvements in industrial energy efficiency.

On the other side, however, it is possible that energy consumption patterns in Sweden have not stabilized. The amount of energy used to support and produce economic activity, as measured by the energy/GNP ratio, has increased in Sweden during the last ten years. The U.S., which uses more energy per unit of GNP, has experienced a flatter trend over the same period. Thus, over time and under favorable supply conditions, Swedish patterns in energy use may approach present U.S. patterns. The current emphasis of Swedish energy policy, however, appears to be toward even greater efficiency improvements and slower growth rates in the future. In addition, the gap between the American and the Swedish standard of living may be different than indicated by the per capita GNP figures, due to the interpretation given GNP as a measure of economic wealth.

Another study* prepared for FEA reinforces the conclusion that structural changes and efficiency improvements in the U.S. economy would be required to obtain the lower energy consumption patterns achieved by some foreign countries. Differences in per capita energy consumption between West Germany and the U.S. are greatest in the household and commercial sector, and the transportation sector. For example, significantly smaller houses, negligible use of air conditioning, point-of-use hot water heating, and other differences result in lower per capita consumption in the West Germany household sector (i.e., about 48 percent of the U.S. level in 1972).

In the automotive sector, per capita energy use per passenger-mile and per capita miles driven are both around 50 percent of the U.S. levels. These factors account for a large portion of the lower per capita consumption in the transportation sector (i.e., about 27 percent of the U.S. level in 1972).

Lower energy consumption in the West Germany and Sweden transportation sectors must, to some extent, reflect the high retail price of fuel. In West Germany, for example, the average retail price of gasoline was more than twice that in the U.S. in 1973.

Additional studies of other countries are planned for the future. These efforts will be undertaken in cooperation with the selected foreign countries and with the International Energy Agency.

Energy Market Analysis

Analysis of the marketplace is necessary to understand how new technologies can have a reasonable chance of competing with other, more established technologies. Successful competition has two main components that are investigated by market analysis: first, the economics associated with energy recovery, transformation, and distribution; and, second, the timing of market introduction and the degree of market diffusion. These studies are patterned after private sector practices, supplemented when necessary by other supporting national and regional analyses.

The Electric Utility Study, started in the summer of 1975 by ERDA, is an example of a specific market study currently under way. This study is the first of several that seek to assess the Plan's overall RD&D objectives, goals, and program priorities from the viewpoint of the industry most directly affected by implementation of new energy technology.

A four-step approach is used in the utility study. First, a range of electric growth futures is established on a regional basis. Provision is made for both high and low total growth rates in electric energy demand. Second, the technical options available to utilities are documented, along with estimates of time schedules and economics. Third, the likely market penetration and resulting benefits of each technology are assessed through an analysis of economic attractiveness from the industry's perspective. This assessment may be repeated for several energy policy scenarios. Fourth, the applicable government RD&D programs are evaluated in light of the market study results to determine whether the program priorities and goals are appropriate.

Tentative findings in the first stage of the study—based primarily on comparisons of technology economics and environmental characteristics—suggest that:

- Conventional coal plants with scrubbers and light water reactors will continue to provide the bulk of base generated power for the rest of the century; gas turbines will provide some power during peak periods.
- The existing and newer technologies will have to compete against these technologies—although few can now be said to offer clear-cut economic advantages (even considering the large uncertainties in cost projections) over coal and nuclear alternatives.
- Three aspects of new technologies make them attractive to pursue: first, the potential for improved

* Richard L. Goen and Ronald K. White, "Comparison of Energy Consumption Between West Germany and the United States," Stanford Research Institute, June 1975.

economics—even small improvements in technology economics can make a large difference when viewed from a national perspective (in light of very large projected markets under all likely growth scenarios); second, the capability of new technologies to meet future, potentially more stringent environmental standards; and third, the ability of some new technologies to shift generation away from oil and gas.
- The RD&D on new technologies now being pursued by the Nation provides more competitors in each area than are likely to be developed by vendors or implemented by utilities.
- One objective of the study will be to lay out an RD&D strategy that provides sufficient technology alternatives in critical areas, but that minimizes investments beyond basic research stages in the less crucial areas. This strategy should provide sufficient alternatives to meet potential future constraints such as the possibility of a nuclear moratorium, major restrictions on western coal mining, or severe constrictions on current environmental standards. In so doing, the strategy should also provide for treating substanial cost uncertainties.

The report on the first stage—indicating preliminary conclusions—will be published in spring 1976; the final report a year later.

The results of the utility study are generally applicable to other energy technology areas as well. They serve to reinforce the commitment to assess all aspects of technology and the barriers to market penetration, as highlighted in this National Plan. In addition, while an adequate set of options must be available to meet unique market needs, priorities within program areas should be established, with emphasis on those options with the highest chance of achieving market success.

Energy, Economic, and Environmental Trade-Offs

The economic and environmental impacts associated with the national energy system and the interrelationships among economic and environmental factors need to be considered jointly. The addition of new energy and supporting systems will cause changes in these impacts, based largely on the mix of technologies that constitute the energy system in future years.

The purposes of the analysis of these trade-offs are to:
- Subject alternative energy scenarios, such as those contained in ERDA–48, to further testing and evaluation.
- Establish a frame of reference for understanding choices among environmental values, energy use, and economic growth subject to conditions of uncertainty.
- Provide information for public discussion on the relative magnitude and interdependence of the impacts associated with energy futures.
- Provide information to program managers and energy planners responsible for developing technological options to achieve energy goals. The emphasis here should be on providing information (such as a set of trade-off curves) that depicts the available options; the sensitivity of options to changes in technology mix, demand levels, and other variables; and the extent to which RD&D can provide solutions to energy, economic, and environmental issues.

The trade-off analysis undertaken by ERDA so far incorporates five factors associated with energy activity: total annual energy costs, including amortized investment, fuel, and operating costs; resources consumed; domestic and imported crude oil requirements; environmental effects; and capital requirements. The analysis is based on various combinations of technologies which could be utilized to satisfy the end-use demands specified in the ERDA-48 scenarios for 2000.

Defining appropriate quantitative measures for the four non-environmental factors above is fairly straightforward even though there are uncertainties in the values. Developing information needed to measure environmental impact is significantly more difficult for several reasons: the multiple types and quantities of environmental damage resulting from particular technologies, the spatial patterns of releases in conjunction with variable natural dilution effects, and the uncertainty concerning the level and costs of specific environmental residuals.

Environmental information with the required degree of precision is not currently available. In addition, damage functions defining the costs to the public of various levels of the pollutants resulting from the full range of different technologies are not available. For this reason, the analysis works with total costs of delivered energy only, rather than with total public cost (with the latter incorporating the external effects of different levels of emissions, as discussed in Chapter II). The results of the trade-off analysis presented here highlight the energy and economic factors.

The first step in the analysis was to determine the lowest possible value for each of the factors given various technology options. In each case, that combination of energy supplies was chosen (subject to the implementation constraints associated with an assumed scenario) which minimized each factor in succession. This analysis is based on meeting a fixed set of end-use demands through variations in fuel substitutions from a given set of energy technologies.

Table VI-4 shows the results of this minimization step. The various technologies used to satisfy end-use demands produced significant variations in the

Table VI–4 Some Preliminary Trade-Off Analysis Results—Effect of Independently Minimizing Each Factor

Factor Unit	Value of All Factors When Each Factor Minimized: Annual Cost	Capital	Imported Oil	Domestic Plus Imported Oil	Resources
Total Annual Cost, $ × 10^9	<u>296</u>	388	304	304	340
Capital Requirements, $ × 10^9	1343	<u>735</u>	1197	1479	1364
Imported Oil, Btu × 10^{15}	0	50	0	0	23
Domestic Plus Imported Oil, Btu × 10^{15}	20	70	20	<u>16</u>	43
Resources Used, Btu × 10^{15}	215	131	123	124	<u>114</u>

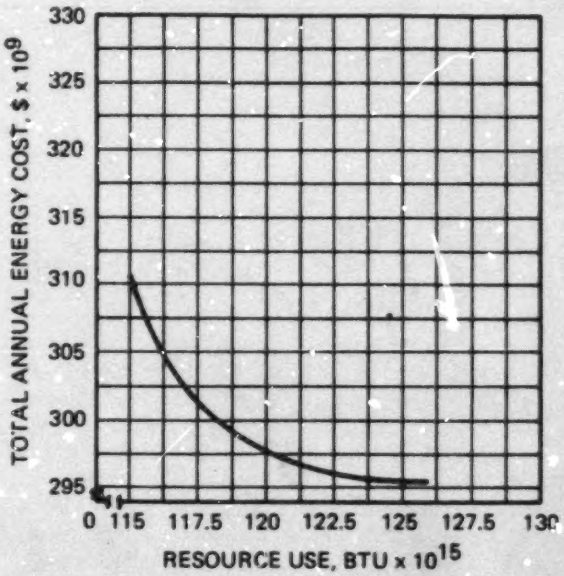
Basis for Calculations: ERDA–48 Scenarios for the year 2000. Underlined values are the absolute minimum values for each factor.

values of some factors and fewer variations in other factors. For example, annual cost has a maximum value of 30 percent above its minimum value while capital requirements exhibit a 100 percent variation and resources consumed only a 15 percent variation.

In the trade-off analysis cases completed so far, total annual costs were minimized subject to constraints on other factors. This process can best be illustrated by considering, for example, the trade-off between the desire to achieve minimum annual costs subject to limits on the amount of resources used. This relationship is illustrated in Figure VI-2. The trade-off presented is typical of those completed to date, with each relationship containing a range of values where small reductions in the constraint cause slight cost increases and further tightening of the constraint causes a more significant cost rise.

The trade-off curves plus the underlying analysis point up several important conclusions:

- **In carrying out its overall mission, ERDA views its job as one of trying to shift the trade-off curve to the left through technology advances.** One example is the achievement of a more desirable (lower) level of resource consumption for lower cost without sacrificing the high standard of living.
- **The interrelationships among environmental quality, energy costs, and public costs need to be examined in much greater detail.** There are many subjective views on what constitutes an adequate level of environmental quality, what additional environmental improvements should be sought, and what the total public cost will be at various levels of energy production and environmental protection. Much more information needs to be developed on environmental/energy/economic interactions, and trade-off curves may be a useful approach for this purpose.



BASIS: ERDA-48 SCENARIOS. THE SHAPE OF THE CURVE REFLECTS THE SUBSTITUTION OF OFF-PEAK ELECTRICITY FOR OIL IN VARIOUS END-USE SECTORS. ELECTRICITY GENERATED OFF-PEAK IS LESS COSTLY THAN OIL BUT CAUSES HIGHER TOTAL RESOURCE CONSUMPTION.

Figure VI–2 Relationship Between Resource Use and Total Annual Cost

Trade-off studies with a more narrow focus are equally important in the context of individual technology programs. Within each program, numerous technical options influence the amount of energy produced or conserved, the associated costs, and the amount of environmental impact. Trade-off studies will be useful in narrowing the list of options to be pursued in the energy RD&D program.

Capital, Manpower, and Industrial Constraints to Energy Growth

The most critical impact of technology introduction on energy and supporting industries will be on certain economic resources (e.g., capital, labor, material, and equipment) associated with facility construction and operation. Constraint analysis addresses the physical constraints associated with these resources and how these resources might influence and be influenced by energy growth and the introduction of new technology. Both technical and nontechnical barriers to technology introduction are important in this analysis. A constraint analysis is being conducted to:

- Identify future changes in economic resource consumption patterns likely to arise from changes in the energy system, especially those likely to require changes in industry infrastructure
- Identify potentially severe disruptions, such as markedly increased needs for skilled craftsmen, to sectors of the economic system
- Provide for a systematic way of analyzing resource requirements (e.g., steel, labor, and money) from energy and non-energy sectors of the economy.

The current effort examines the capital, manpower, material, equipment, and construction requirements associated with the alternate supply and demand policies discussed previously in the energy/economic growth section. The required resource levels were obtained from a model developed by the Bechtel Corporation.*

The constraint analysis effort is just beginning. Based on the initial calculations, it appears that:

- The ratio of energy capital investment to total business investment (historically between 25 and 30 percent) would remain relatively constant over a broad range of near-term (to 1985) energy futures. In one scenario examined, heavy investments in synthetic fuel facilities were offset by declining transportation investments (e.g., tankers) for imported oil and gas.
- A tight labor market will continue for certain construction trades—namely, pipefitters, welders, boilermakers, and electricians. However, overall manpower demands by energy industries should not have severe effects on the total manpower market.
- The current ability of industry to modify existing manufacturing and other production facilities to reflect the requirements associated with new energy technologies is not clear and must be more thoroughly investigated. For example, new technology places large demands on special products such as heavy steel plates, but this appears to require relatively small additional capital investments in the energy sector.

The results of this constraint analysis will highlight areas where more detailed and narrowly focused studies are appropriate; for example, studies that address specific industries, products, or skills. Planned ERDA efforts include the development of an overall manpower data base for energy-related activities and sources, and the analysis of manpower requirements for future energy technologies. These efforts will be coordinated with other Federal agencies having ongoing programs in manpower-related areas.

Need for Continuing Studies

The results of all of these continuing studies and analyses simultaneously provide a perspective for planning, an opportunity to test or to make concrete some of the underlying assumptions of the Plan, and a means for extending the understanding of the attributes of different approaches and outcomes through time to deal with the energy problem. Missing information and uncertainties highlight the need to acquire the specific data or to define the specific relationships. Studies throughout the Federal structure, in universities, in the private sector, and in other countries all contribute to this process. As with all analyses, these approaches need external discussion and the discipline of the peer review process. The desired end results are greater knowledge and a guide to effective future action.

* M. Carasso, J. M. Gallagher, K. J. Sharma, J. R. Gayle, R. Barany, "The Energy Supply Planning Model," Bechtel Corporation, San Francisco, California, August 1975, Volumes I and II.

Chapter VII—Future Evolution of the Plan

The National Plan for Energy RD&D is designed to provide the framework for carrying out governmental policy in the development of conservation and energy supply technologies. ERDA-48 set forth the fundamentals of the Plan, including a diagnosis of the national energy problem, the five major national goals related to energy, and the energy technology goals. Further, the Plan presented a strategy for achieving these goals, along with broad program objectives. Finally, the Plan included the judgmental priorities for developing the major sources of energy.

In ERDA-76-1, the Plan has been expanded in scope and in depth of coverage. The basic goals and strategy have been refined somewhat, but remain essentially intact. ERDA-76-1 emphasizes the operational aspects of implementing the Plan, particularly in the areas of market penetration of new technologies, Federal interaction with other institutions of the national economy, and an overall approach to detailed analyses and planning of Federal RD&D programs.

But no one document can cover all the areas that make up the complex energy RD&D spectrum; not even in the aggregate can the two documents (ERDA-48 and ERDA-76-1) claim completeness. Thus, future planning efforts will build on these efforts, adding new information as it becomes available and gradually incorporating more of the elements that must be considered in creating a unified Plan. Although it is too early to state with certainty what will be included in future reports, three activities are essential to ERDA's own planning and will likely be included in the next Plan update: (1) developing energy RD&D costs and benefits; (2) establishing priorities for component programs; and (3) analyzing energy RD&D activities in the private sector.

Developing Energy RD&D Costs and Benefits

The major energy technologies have not been subjected to a detailed review of costs and benefits, although cost-benefit studies of some options have been done. Such assessments are complicated by the fact that alternative technologies cannot easily be compared with each other, since each tends to interact simultaneously with many others. The ERDA-48 scenarios exemplify this problem. However, tools for overcoming these complexities—tools such as venture analysis, economic impact analysis trade-off studies, net energy analysis, and constraint studies—are becoming available. **It is ERDA's goal to apply these tools during 1976 to achieve a more systematic approach to quantification of the costs and benefits of selected energy technologies, and to report the results of this work in the next Plan.**

Establishing Priorities for Component Programs

The Program Planning, Budgeting, and Review (PPBR) system discussed in Chapter V is being designed to increase the relevance and effectiveness of ERDA's programs. One of the key results of this process is the ability to establish more definitive priorities for energy system technology options. Currently, only the major categories of energy conservation and supply technologies have been ranked. Future efforts will focus on ranking, in order of priority, component programs aimed at the same or similar markets. For example, the electric utility study currently in progress and summarized in Chapter VI is aimed at ranking technologies that compete for the electric utility market; future analysis will analyze other market sectors. For example, there are a number of technological approaches to producing low-Btu gas from coal; these and other technologies need to be evaluated further to identify their relative merits for the gas utility sector. However, because of the multiple uncertainties existing in many of the program areas, a comprehensive ranking cannot be achieved within the next year. ERDA is initiating the task and will pursue the assessments as rapidly as possible. **It is ERDA's goal in 1976 to take the first step—more definitive analysis of component programs in a number of key areas aimed at the same or similar markets.**

The results of this analysis also will enable ERDA to specify more accurately the objectives of each component program and of the overall tech-

nologies. These refined objectives will be more specific with respect to achieving control of environmental releases, costs of energy production, and improving reliability and efficiency. These assessments will apply to all energy RD&D projects, whether they are being developed primarily in the private sector, in ERDA, or in other government agencies; consequently, they should help in deciding the extent and timing of private and/or public assistance necessary for the development of energy technologies. Nevertheless, the market will ultimately determine the attractiveness of implementing any one technology.

Analyzing Energy RD&D Activities in the Private Sector

Private sector RD&D activities are critical to the development and the ultimate market penetration of energy technologies. However, because government may need to reinforce and assist these private activities, those who design government policies and programs must understand where the private sector is using its own RD&D funds.

This objective necessitates an ongoing analysis of private sector energy RD&D activities. The results of this analysis, coupled with federally derived information, will be a factor in planning the optimal allocation of resources required to finance the projects and programs that will meet national energy RD&D goals and objectives.

Present data collection and analysis methods need to be supplemented to provide more meaningful analysis of the private sector RD&D effort in energy. An appropriate framework will be designed for collecting additional data. Among the important elements of the framework are the problems the effort addresses; the goals of the research effort; its relationship to the broader plan and to other research efforts under way; broad project characteristics and descriptions; funding and cost estimates; time period over which success is sought; and plans for future efforts.

ERDA will initiate a dialogue with and solicit the voluntary cooperation of industry and industrial organizations to develop factual information that will provide ERDA with needed insights, yet protect sensitive or proprietary information of private companies. ERDA welcomes private sector views on appropriate mechanisms for collecting this information.

It is ERDA's goal to initiate in 1976 a more intensive effort to acquire knowledge of private sector RD&D efforts in energy; to apply the knowledge to Federal RD&D planning; and to provide an interim report in the Plan issued next year.

Appendix A
Perspective on World Resources

Following the events of October 1973, the world energy crisis was viewed as a problem of immediate shortage. Attention soon shifted, however, first to the issues of pricing and other terms of availability, and then to the broader issues of international economic relations and world monetary problems. Although these issues have not yet been resolved, energy problems are beginning to be viewed from a longer term perspective. Triggered by less specific events, the oil crisis is also being interpreted as symptomatic of changes long in the making. Attention is finally being redirected to the more fundamental issues posed by a growing world population demanding ever-increasing amounts of energy.

One element of the energy problem is the geographical location of energy resources and their availability for development and worldwide distribution. The importance of regional availability to the consuming countries was made manifest by the assertion of control over energy operations by producing and exporting countries. Table A-1 summarizes the present situation with respect to world

Table A–1 Estimated Recoverable Reserves of Coal, Petroleum,* and Natural Gas

Region	Coal	Percent of Total Coal	Petroleum	(In Quads) Natural Gas	Total Oil & Gas	Percent of Total Oil & Gas	Total Coal, Oil & Gas	Percent of Total Coal, Oil & Gas
United States	4,900	34.3%	246	244	490	7.6%	5,390	25.9%
Other North America	142	1.0%	71	80	151	2.3%	293	1.4%
South America	50	0.3%	157	65	222	3.4%	272	1.3%
Subtotal, Western Hemisphere	5,092	35.6%	474	389	863	13.3%	5,955	28.6%
Middle East	35	0.2%	2,343	700	3,043	46.8%	3,078	14.8%
North Africa	neg.	0.0%	227	260	487	7.5%	487	2.4%
Middle Africa	69	0.5%	169	65	234	3.6%	303	1.5%
South Africa	292	2.0%	neg.	neg.	neg.	0.0%	292	1.4%
Western Europe	1,374	9.6%	150	210	360	5.5%	1,734	8.3%
Eastern Europe	1,073	7.5%	17	20	37	0.6%	1,110	5.3%
U.S.S.R.	3,325	23.3%	480	580	1,060	16.3%	4,385	21.1%
China	2,222	15.6%	145	25	170	2.6%	2,392	11.5%
South & East Asia	351	2.5%	110	75	185	2.9%	536	2.6%
Oceania	460	3.2%	13	45	58	0.9%	518	2.5%
Subtotal, Eastern Hemisphere	9,201	64.4%	3,654	1,980	5,634	86.7%	14,835	71.4%
World Total	14,293	100.0%	4,128	2,369	6,497	100.0%	20,790	100.0%
Percentage of Total	68.7%		19.9%	11.4%			100.0%	

* Includes natural gas liquids when data were available.

Tabular data derived from the following sources:

(1) All data for the United States are from the U.S. Geological Survey.
(2) World Energy Conference, 1974.
(3) "Changes Restructuring World Oil," The Oil and Gas Journal, December 30, 1974.
(4) "Productive Capacity Grows as World Demand Falters," World Oil, August 15, 1975.

Note: Data generally include measured and indicated reserves as of January 1, 1975, although in some regions data are not sufficiently well defined to assure the intended comparability. Coal data are reported in energy units. Where other reserve data were not reported in energy units, conversion from physical units was based on standard conversion factors per barrel of oil or cubic foot of gas.

recoverable energy reserves of conventional fossil fuels by type and by geographical location. These data refer to known or already discovered quantities that can be economically recovered with existing technology.

The outstanding feature of world fossil fuel reserves is their pattern of geographical concentration. For example, petroleum and natural gas reserves are largely concentrated in the Eastern Hemisphere, with over half of the world's total in the Middle East and North Africa, and most of the remainder in the Soviet Union. The U.S. has the next largest reserves of oil and gas. However, despite the large Canadian and Venezuelan producing industries, the oil and gas reserves of the Western Hemisphere represent only 13 percent of the world total.

Energy Consumption Patterns

The most important aspects of the world energy situation are (1) the dependence of most of the world on petroleum, and (2) the concentration of both oil and other fossil fuel resources in relatively few countries. Developed countries, other than the centrally planned (Communist) economies, rely on oil and gas for three-fourths of their needs. The same is true of the less developed countries, but with their limited access to natural gas, oil alone accounts for over 60 percent of their total commercial energy supplies.

Coal is still a principal energy source in the centrally planned economies, where it supplies about one-half of the total energy consumed. At the same time, the use of oil and gas has been increasing rapidly, rising from about one-fourth of total energy use in Communist countries in the early 1960's to almost one-half of the total currently.

In spite of rising costs, the worldwide trend toward greater dependence on oil and gas is likely to continue unless affirmative action is taken to increase the use of coal and development of alternative sources. The prospects for coal are not encouraging in many countries since the incentives and advantages continue to favor rapid development of oil and gas resources. Many other countries without coal or other fuel resources have no tenable alternative to imported oil due to their limited capability to develop other sources or the new technologies needed to use renewable resources such as solar energy.

Problems of Trade and Distribution

World consumption patterns reflect the geographical location of energy resources and the system of trade or distribution that has served to link consuming and producing areas. The highly integrated and efficient global systems of transport, processing, and distribution of petroleum that developed after World War II were, in many ways, more remarkable than the development and expansion of the oil-producing operations. If this distribution system were to break down or become a less effective means of linking producers and consumers, global problems of balancing supply and demand would appear as segmented regional problems, with persistent shortages in some areas and surpluses in other—especially producing—areas.

This was apparent in the situation in 1975, when widespread oil surpluses were a result of higher costs to countries with payment difficulties and the world-wide slowdown in economic growth. The rapid introduction of supplies from new producing areas, such as the Alaskan North Slope and the British and Norwegian sectors of the North Sea—each scheduled to deliver about 2 million barrels daily by 1980—could reinforce and extend the surplus situation. While such a surplus situation is likely to be of limited duration, it may lead to improper interpretations of basic energy supply prospects for the longer term. All of the underlying difficulties and elements for future crises will remain unless there are continuing efforts to reduce the heavy dependence upon relatively scarce world petroleum resources.

As Dr. V. E. McKelvey, Director of the U.S. Geological Survey, recently pointed out, one of the wide-ranging effects of the oil crisis:

> . . . has been to convey an appreciation of the fact that a steadily expanding petroleum supply is not something to be taken for granted. . . . Whatever else it may have done, the Organization of Petroleum Exporting Countries' action served as a timely reminder that even the fabulously productive fields of the Middle East are exhaustible, and that plans must be made for an orderly transition to other sources of energy as the inevitable process of depletion makes oil progressively more scarce and costly. The timing and course of the transition depend heavily upon the relative availability of the various energy sources, including petroleum. (McKelvey, 1975, p. 27)

Obligations of the Industrial Countries

While the majority of the less developed countries of the world must import the bulk of their energy (mainly oil), the industrialized countries of Western Europe, the U.S., and Japan account for about 75 percent of the total intercontinental trade (imports) of petroleum. If oil and natural gas reserves are to be extended through either conservation in use or the development of alternative sources, this extension must be effected in the highly developed industrialized countries. In the U.S. and to a lesser extent in Europe, coal is available as an alternative fuel. Neither Japan nor most of the less industrialized world has this alternative.

The prospects for imported coal becoming a practical alternative to oil seem very unlikely for

countries lacking their own domestic coal sources. Aside from the problems inherent in the geographical location of the surplus reserves, extraordinary difficulties are involved in moving and using coal in most of the resource-deficient countries. While Japan imports a sizable quantity of coal, it is mainly for special use in the steel industry and not as a basic general-use fuel.

Most energy-deficient countries have found no readily available alternative to continued imports of oil, and no alternative is likely unless initiatives are taken through vigorous R&D programs in the most technologically advanced countries. Successful development of alternatives could ease the world energy situation in several ways:

- First, if conservation and new technologies were vigorously applied in the industrial countries, the total world demand on the reserves of the Middle East and other export areas could be decreased significantly.
- Second, technologies developed in the industrial countries, especially those using renewable resources such as solar energy, wind, and water power, might be adapted for use elsewhere.
- Third, some of the lower quality energy sources still undeveloped, such as oil shale and tar sands, might be exploited with the assistance of those countries that are technological leaders.
- Finally, improved methods of exploration and development of conventional fossil fuel resources could expand the world's reserves and improve distribution.

It is possible that extensive resources of the conventional fuels can be found outside of the established producing areas. Estimates of undiscovered recoverable resources indicate that the ultimate production of oil, gas, and coal will be far beyond that implied in the estimates of reserves in Table A-1.

Estimates of World Resources

Reserves are essentially the proven inventory that producers must have on hand to continue operations. Therefore, the most surprising characteristic of existing world reserves is not how small but how large they are. Based on world rates of production in 1974, the total reserves of petroleum would last for another 35 years and the world coal reserves shown in Table A-1 would last for about 175 years. Yet, these global averages are deceiving because not all producers have equal call on the existing stock, and, further, demand can be expected to increase in the future.

It is generally expected, however, that additional resources will be located and moved into the reserve category in the established producing areas. For example, in the Middle East where the potential producing areas are generally well defined, some estimates suggest that the presently published petroleum reserves of some 400 billion barrels may ultimately be at least twice as large ("Middle East Oil Reserves," 1975, pp. 369–371). The U.S. Geological Survey estimates that in addition to the 45 billion barrels of U.S. proven reserves of liquid fuels there may be some 30 billion barrels of inferred reserves and anotner 60 to 150 billion barrels of undiscovered resources. Similarly, estimates of the undiscovered South American potential are about double the current reserves.

There is great current interest in the growing potential of offshore production of oil and gas. The U.S. Geological Survey estimates that U.S. offshore recoverable oil resources yet to be discovered may range from 10 to 50 billion barrels.* In the North Sea, where published oil reserves are generally shown to be 20 to 25 billion barrels, ultimate recoverable resources are being placed at 45 to 78 billion barrels (Turner, 1975, p. 158). Estimates of ultimate recoverable oil resources for the Canadian offshore, including the Arctic, are many times their current reserve estimate. There is also considerable interest in developing the offshore resources in other parts of the world.

Total resources of coal are much more easily authenticated than oil or gas resources. The total world coal resources have been estimated at more than seven times the world reserves. Table A-2 summarizes some of the available resource estimates and compares them to reserve estimates. In a comprehensive survey of world energy resources (World Energy Conference, 1974), world coal resources were estimated at 12 trillion short tons, perhaps one-half of which would be recoverable. Others (Averitt, 1975) have indicated that the world total, including "hypothetical resources," could exceed 16 trillion tons, with some 4 trillion tons located in the U.S. Coal resources occur mainly in areas above 30 degrees N. latitude, with more than one-half of the total in the Soviet Union and China. North America, Europe, and Australia account for most of the remainder.

As Table A-2 indicates, total resources of each mineral fuel are estimated to be a multiple of (usually several times) the volume of reserves. This is to be expected since resource estimates include extrapolations of amounts in existing proven areas and speculations about other potential discoveries. Unless properly interpreted, however, data on resource estimates can be misleading. For example, not only is the existence of these resources uncertain but, in many cases, great advances in technologies are required before the resources can be located, devel-

* Included in the 60 to 150 billion barrels of undiscovered recoverable resources noted above.

oped, and used in environmentally acceptable ways. It is vitally important that these technologies be developed in a timely fashion and that science and technology be committed to the more challenging tasks of finding ways for efficient and economic use of renewable and essentially inexhaustible resources.

Table A–2 World Reserves and Resources of Mineral Fuels

Resource	Units*	Reserves	Total Recoverable Resources**	Sources
Coal	10^9 tons	665	6,000–8,000	(1)(2)
Crude Oil	10^9 bbls	700	1,300–1,880	(3)(4)(5)(6)
Natural Gas	10^{12} cu. ft.	2,300	3,000–6,000	(3)(4)(8)
Oil Shale	10^9 bbls.	500	1,125–16,000	(1)(7)
Bitumen Rocks	10^9 bbls.	350	1,000–2,500	(1)(8)
Uranium (U_3O_8)	10^3 tons	3,500	5,000–6,500	(1)(9)
Thorium (ThO_2)	10^3 tons	400	1,500–3,450	(1)(9)

Note: Comparisons between and among the resource categories on a common-unit basis such as quads are not advisable because of the widely varying methods of estimating and reporting data and the fundamental differences as to the technical feasibility of exploiting and using the several mineral fuels.

* Conventional U.S. units
** Including reserves
(1) World Energy Conference, Survey of World Energy Resources, 1974.
(2) Averitt, U.S.G.S. Bulletin 1412.
(3) "Changes Restructuring World Oil," The Oil and Gas Journal, December 30, 1974.
(4) "Productive Capacity Grows as World Demand Falters," World Oil, August 15, 1975.
(5) Lawrence and Farrar, 1975, p. 63.
(6) Linden, Institute of Gas Technology, 1975.
(7) Culbertson and Pitman, U.S.G.S. Professional Paper 820.
(8) McKelvey, "World Energy Reserves and Resources," Public Utility Fortnightly, September 25, 1975.
(9) Energy Research and Development Administration estimates.

Appendix B
Net Energy Analysis of Nuclear Power Production

The purpose of this appendix is to present the first of a series of net energy analyses on the major energy technologies being pursued by ERDA. Nuclear power has been the subject of much recent discussion and was chosen for the first study. The analysis addresses the amount of electricity generated by a nuclear plant relative to the amount of external energy required to construct, fuel, and operate the plant.

This appendix briefly discusses the underlying concepts of net energy analysis; presents the analysis of electrical power from a light water nuclear reactor; and reports the results of studies by the State of Oregon, the Center for Advanced Computation of the University of Illinois (Pilati and Richard), Development Sciences, Inc., and the Institute for Energy Analysis.*

The present analysis draws from these studies and arrives at the same general conclusion—that a nuclear power plant produces substantially more energy than is required to construct, fuel, and operate the plant. The major conclusions are:

- The direct and indirect external energy inputs are about 26 percent of the energy output. This value is within the range of values for electrical generating facilities fueled with conventional fossil fuels.
- Uranium enrichment, using the diffusion process, accounts for about 91 percent of all direct energy inputs and for 72 percent of all direct and indirect energy inputs. Use of the gas centrifuge process now being developed would significantly reduce the energy required for enrichment. The construction and operation of the power plant account for another 16 percent.
- The internal energy loss due to the thermodynamic efficiency of a nuclear plant is about 68 percent. This means that the nuclear fuel must generate 3,000 Btu of energy in order to produce 1,000 Btu of output as electricity.
- According to two 1975 studies (Development Sciences, Inc., and Oregon), 6,000 to 7,000 Btu of resource base must be available in order to have the 3,000 Btu energy input to the reactor. This additional resource base is necessary to allow for uranium not recovered during mining or lost during processing, and the fissionable uranium left in the tails during the enrichment process. However, all the 3,000 to 4,000 Btu of energy remaining are not irrevocably lost or consumed; much of the energy may be utilized in the future if the economics of processing these resources become attractive.

* See the bibliography for detailed references.

General Methodology

In net energy analysis, selection of the appropriate boundaries for the analysis is difficult.** A simplified boundary categorization cuts the issue into horizontal and vertical sets. The horizontal set encompasses the energy production (transformation) processes from resource extraction to point of distribution. The boundary of this set can be extended at the point of extraction to include the resource base that was not recovered during extraction. At the other end, the boundary can be extended to incorporate the local distribution of energy and the energy losses in the end-use devices.

The vertical set centers around the direct energy inputs, either electrical or thermal, externally *** re-

** In addition, the analysis may be either static or dynamic with respect to the time-phased aspects of the energy expenditures and outputs.

*** External energy is the energy required from sources outside the transformation process being investigated. For electric power plants (the final production transformation process in a sequence that starts with mining the fuel resource), the external energy required includes the energy used to build, equip, and operate the plant, but does not include the internal energy lost (as waste heat) in the conversion of thermal energy to electrical energy. That is, the energy content of the burned fuel is not counted as an external energy input. The energy content of the fuel is counted, however, in calculations on the amount of resource base required to provide a certain level of energy in the desired form (in the example here, electrical energy).

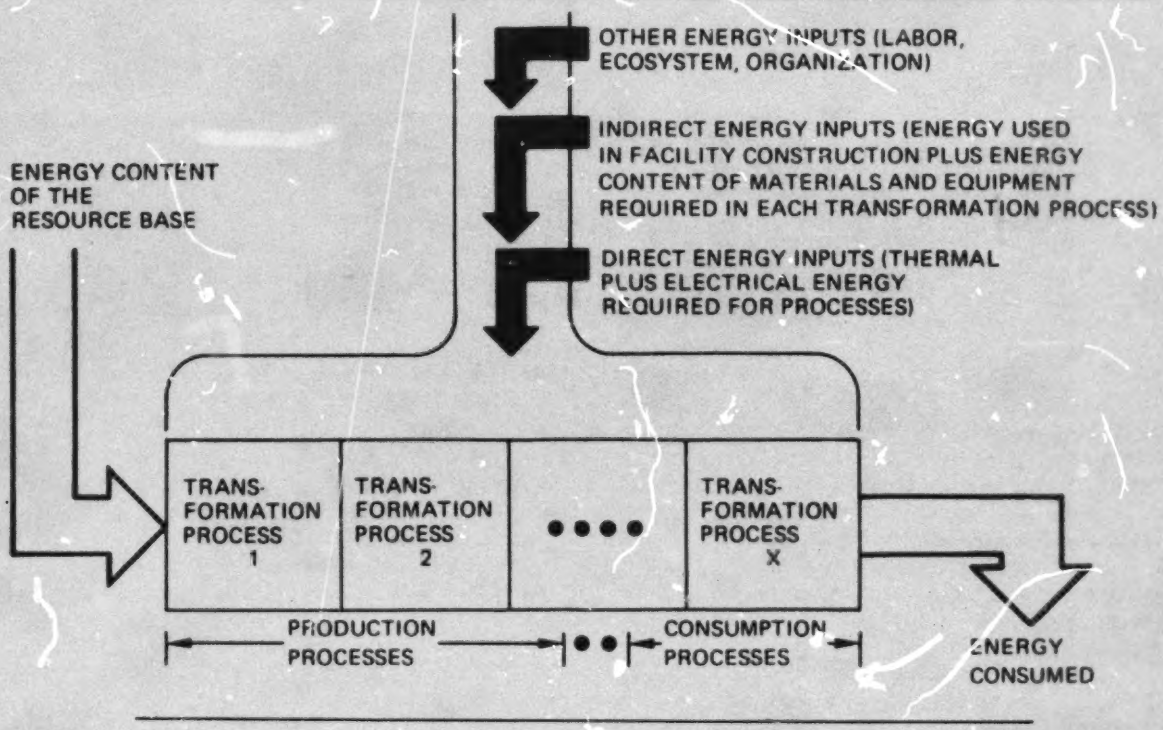

OTHER ENERGY INPUTS (LABOR, ECOSYSTEM, ORGANIZATION)
INDIRECT ENERGY INPUTS (ENERGY USED IN FACILITY CONSTRUCTION PLUS ENERGY CONTENT OF MATERIALS AND EQUIPMENT REQUIRED IN EACH TRANSFORMATION PROCESS)
DIRECT ENERGY INPUTS (THERMAL PLUS ELECTRICAL ENERGY REQUIRED FOR PROCESSES)
ENERGY CONTENT OF THE RESOURCE BASE
TRANS-FORMATION PROCESS 1
TRANS-FORMATION PROCESS 2
TRANS-FORMATION PROCESS X
PRODUCTION PROCESSES
CONSUMPTION PROCESSES
ENERGY CONSUMED

Figure B–1 Conceptual Boundaries for Net Energy Analysis

quired to execute a step in the horizontal set. The boundaries of the vertical set can be extended to include the indirect external energy required for facility construction and the energy required to produce materials directly employed in the processes. These items include the energy used in producing equipment and materials (e.g., steel, paper, sulfuric acid) that are then used to build and operate an energy producing plant, and the energy lost during process stages (e.g., scrap fuel, thermal conversion, transmission). The vertical boundary can also be extended to include the energy embodied in the labor, the ecosystem, and the organizational infrastructure that was necessary to support the energy production process at each stage. Figure B-1 shows the boundary possibilities.

Multiple definitions of energy systems boundaries, combined with legitimate differences in assumptions and concerns about the addition of different energy forms (with different preference values), cause net energy results to vary. Several studies have attempted to define a variety of ratios, net summations, or other measures that are closely related to a particular question about energy efficiency. However, too heavy reliance on a single number, or ratio, to define the net energy of a particular technology misses the most important point of net energy analysis—to provide information on technology options as a supplement to other important economic and technical data and analysis.

Specific Methodology for Nuclear Power

For the example case on nuclear power, the net energy calculations include the first-order effects of direct fuel inputs and the second-order effects of energy losses and energy inputs into equipment and materials. These are the external direct and indirect energy inputs. The direct effects are calculated through the use of process analysis, where the quantities of energy used for each activity in the production process are determined. In some instances, these figures have been determined using an engineering flow sheet of the process; in other cases, an estimate is obtained by measuring the expenditures for energy during a period of time and dividing by the average price for energy during the same time period.

The indirect energy requirements are computed through the use of a 357-sector Input-Output model* that relates each fuel-producing and fuel-consuming sector to each other one. The model can be manipulated mathematically to account for energy requirements from the many sectors that contribute to the

* C. Bullard and R. Herendeen, **Energy Costs of Goods and Services, 1963 and 1967**. Document 140, Center for Advanced Computation, University of Illinois Urbana, 61801, March 1975.

equipment and materials used in the nuclear fuel process. This tool saves the effort that would be expended to conduct a process analysis for every production sector of the economy.

The energy embodied in labor, ecosystems, and organizational infrastructure is not included in this example. Early results (see University of Oklahoma, 1975, Appendix B to Chapter 15) from an analysis of the ecosystem energy inputs on another technology tend to show that the ecosystem energy contribution is of a lower magnitude than the other energy inputs. Also, labor and infrastructure energy inputs are not well documented.

The steps of the nuclear power production process included in the case example are: mining, milling, conversion, enrichment, fuel fabrication, power plant construction and operation, fuel storage, waste storage, and transportation for each stage of process.

The energy requirements for each of the nine process stages are shown in Table B-1 in terms of the three components of external energy inputs: direct fuels, energy for construction, and energy for materials. This disaggregated presentation serves two purposes: (1) to permit the determination of the quantitatively important items as compared to items that are less significant and (2) to begin focusing attention on those processes where efficiency improvements can be made.

The energy content of the uranium left in the ground relative to the amount recovered under present extraction techniques is not included in this example. Most uranium mining is open pit and almost all of the uranium is captured in the mining process. For deep mining, significant uranium resources would remain in the ground, but it is not clear whether this value should be added to the other values. This uranium reseource has not been lost or used up and can be recovered, at some higher cost, in the future. Further discussion of this point is presented later in this Appendix. In addition, the analysis does not consider the net energy implications of electricity usage beyond the electric generating station. Thus, transmission losses and the efficiency of end-use devices are not included. However, for the purpose of comparing various fuels for supplying electricity these losses would be identical, and therefore, would not affect any conclusions based on these analyses. The analysis also does not include plant decommissioning requirements, but they are thought to be small. Also not included is the residual energy still available in the plant and fuel after 30 years of operation.

Detailed Calculations

The energy required for each step in the fuel cycle (Table B-1) has been determined for a 30-year life,

Table B–1 Energy Requirements for a Large Nuclear Power Plant

1000 MWe Pressurized Water Reactor—No Recycle—0.20% Enrichment Tails Assay 30 Year Life—61% Average Capacity Factor—160,300,000 MWh Output (547 Trillion Btu)*

Process	Quantity	Electrical Inputs, in MWh			Thermal Inputs, in Millions Btu			Total Inputs, Billion Btu **
		Direct	Materials	Construction	Direct	Materials	Construction	
Mining	3909 MTU	47,760	22,050	6,210	1,005,000	621,500	441,500	2,935
Milling	3909 MTU	67,430	16,140	2,780	1,310,000	621,500	121,200	3,037
Conversion	3909 MTU	39,830	16,620	620	4,826,000	426,000	29,000	5,334
Enrichment	3124×10^3 SWU	3,778,000	18,120	24,050	1,048,000	428,000	1,016,400	103,037
Fuel Fabrication	683 MTU	67,750	137,200	600	147,900	1,579,000	26,000	4,096
Power Plant Construction and Operation	30 years	0	256,500	205,000	378,000	8,179,000	9,583,000	23,401
Fuel Storage	683 MTU	7,280	2,430	3,880	4,560	64,300	174,300	240
Waste Storage	30 years	130	4,560	320	2,080	158,200	22,950	398
Transportation								
—Natural	3909 MTU	0	410	0	31,900	24,470	0	61
—Fuel	693 MTU	0	1,546	0	120,300	92,290	0	230
Totals		9,008,000	475,600	243,460	8,874,000	12,195,000	11,414,000	142,769

*Electricity converted to thermal equivalent at 3413 Btu per kilowatt hour
Legend: MTU—Metric tons uranium
SWU—Separative work units (directly proportional to the energy required in the enrichment process)

**Electricity converted to thermal equivalent at average heat rate of 11,400 Btu per kilowatt hour

Note: The conversion of electrical to thermal units plus the addition of thermal inputs from different energy sources ignores the quality aspect of preferred fuels. This is a serious shortcoming, as there is no single factor that is satisfactory for converting different energy sources to an equivalent base.

Source: Institute for Energy Analysis with adjustments by ERDA.

Table B–2 The Energy Requirements for Light Water Reactor Nuclear Fuel Cycle Elements

Process	Equivalent Thermal Energy (Trillion Btu)	Percentage of Total
Mining	2.935	2.1
Milling	3.037	2.1
Conversion	5.334	3.9
Enrichment	103.037	72.1
Fuel Fabrication	4.096	2.9
Power Plant Operation	23.401	16.4
Fuel Storage	0.398	0.3
Waste Storage	0.240	0.2
Transportation		
—Natural U	0.061	0.1
—Fuel	0.230	0.2
Totals	143*	100*

* Rounded

1,000 Megawatt electric (MWe), pressurized water plant utilizing conventional uranium ores and a 0.20 percent enrichment tails assay. It is assumed that the spent fuel is **not** reprocessed to recover the unused uranium and plutonium. These energy requirements include the direct and indirect inputs of both electricity and thermal energy. Indirect requirements cover the energy content of the materials required plus a prorata share of energy used to construct the plants needed for the fuel cycle. Energy requirements for third and higher orders of processes, obtained by tracing the energy content of materials and equipment back to the resource base, have been found to be very small compared to these first- and second-order energy inputs, and have therefore been ignored. It is assumed that the plant generates electricity on the following capacity schedule:

1. Five-month period prior to being declared commercial—40 percent
2. First two years as a commercial plant—65 percent
3. Years 3 through 15—70 percent
4. Last 15 years—decreases 2 percentage points per year from 68 percent in year 16 to 40 percent in year 30.

The lifetime output of the plant while operating according to the assumptions used here is 160,-300,000 MWh, or 547 trillion Btu. The external energy inputs required are 143 trillion Btu, or 26 percent of the output.

Table B-1 shows that the uranium enrichment step is clearly the dominant energy consumer of all the nuclear fuel cycle steps. It consumes 97 percent of direct electrical inputs and accounts for 91 percent of total electrical requirements. If all energy inputs are summed by converting electrical inputs to thermal equivalents, the enrichment step is found to require 72 percent of all energy inputs. This is shown in Table B-2. Construction and operation of the power plant account for 16 percent of energy requirements and all other steps combined account for about 12 percent.

Conclusions

The nuclear option is clearly a net producer of energy. The results of this analysis are for the case where plutonium and spent uranium are stored rather than recycled and with an average lifetime capacity factor of 61 percent. The system as described requires 262 units of input to provide 1,000 units of output to the bus bar. Recycling spent fuel, improving plant utilization, and operating the enrichment plant at a tails assay above the assumed 0.20 percent would improve the energy efficiency. For example, a capacity factor of 75 percent instead of 61 percent reduces the energy input requirement by 5 percent. An enrichment tails assay assumption of 0.30 percent instead of the 0.20 percent used would lower energy input requirements by 15 percent.

The results of studies by others are similar to those reported in this analysis and are summarized in Table B-3.

The most promising area for improving the net energy position of the light water reactor system is to reduce the energy consumption of the enrichment step. The data used for this exercise assume enrichment by the current gaseous diffusion process. Development is well along on the centrifuge process, which is expected to reduce the direct requirement for electricity by a factor of ten. Other more advanced processes are in the conceptual stage. The introduction of recycle would also reduce energy input requirements since less enrichment would be required and smaller quantities of ore would need to be mined.

The net energy discussion above has focused on the quantity of external energy that must be invested in extracting, processing, and transporting fuels, and building and operating the industrial complex used to

Table B–3 Comparison of Net Energy Results

Investigator	Units of External Energy Input Per 1,000 Units of Output
Development Sciences, Inc.	238
State of Oregon Study	194*
University of Illinois, Center for Advanced Computation (Pilati and Richard)	210
Institute for Energy Analysis	248
ERDA–76–1	262

* Adjusted to comparable basis

generate energy. Other analysis approaches are also useful for understanding energy transformation processes. Two approaches, dynamic net energy analysis and analysis of the resource base, are discussed below.

Dynamic Analysis

A dynamic analysis of the direct and indirect external energy expenditures and the energy output of nuclear power plants as a function of time has been completed. This analysis indicates that:

- The external energy expenditures required to build, fuel, and operate each plant are recouped early in the second year of commercial operation.
- The net energy obtained from nuclear power from 1973 to 1985, under an assumed construction schedule based on ERDA-48 scenarios, is strongly positive.

External energy expenditures start about 5 years prior to plant operation, when major construction activities begin. The expenditures accelerate in the third year prior to commercial operation due to mining, milling, transport, and conversion of uranium needed for the initial reactor fuel core. Uranium enrichment and fuel fabrication expenditures occur during the second year prior to commercial operation. During the first year prior to commercial operation, a slight positive flow of energy takes place as a result of the electrical energy generated during pre-commercial operation testing. This energy exceeds that required to complete construction, operate the plant for five months, and provide for mining, milling, transport, and conversion of the uranium needed for the first reload.

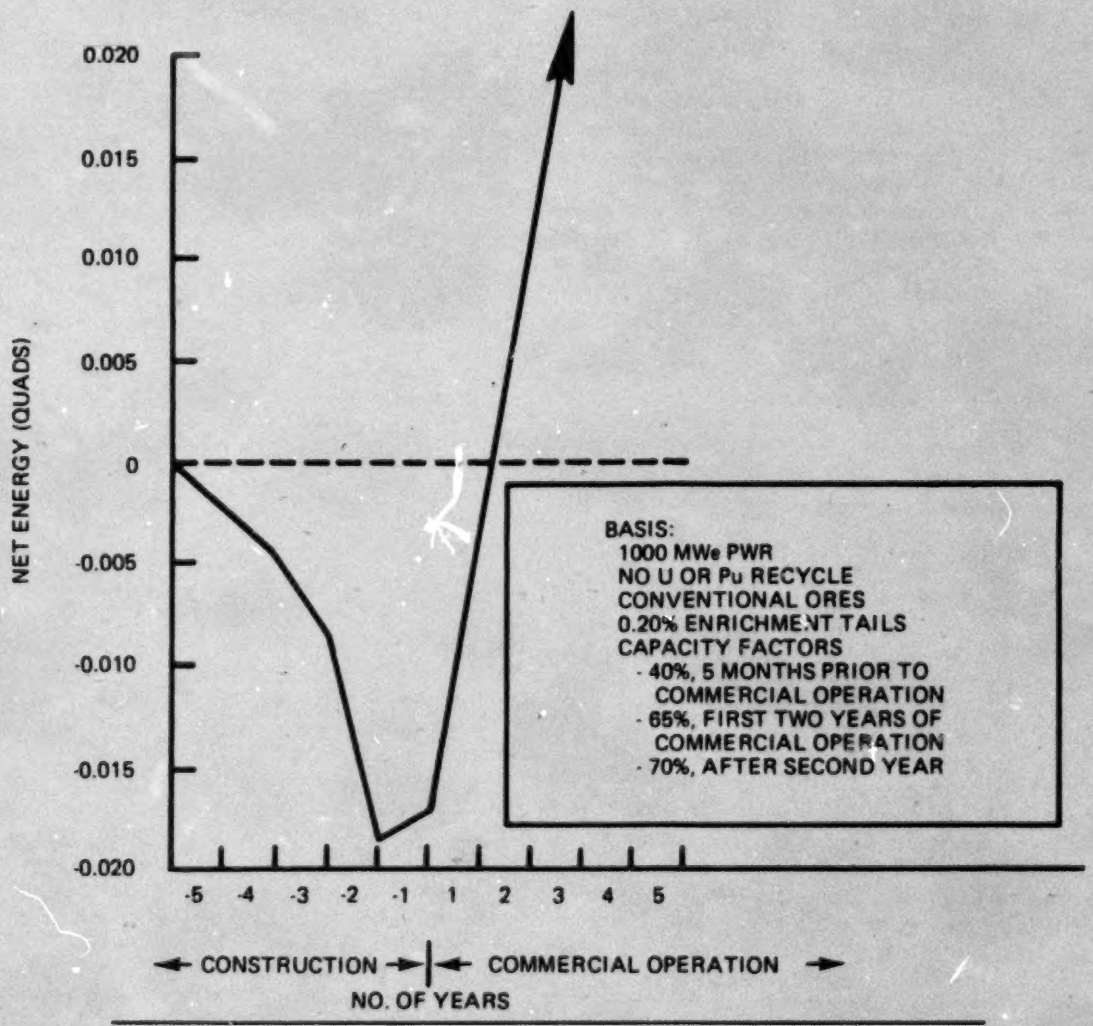


Figure B–2 Dynamic Net Energy Analysis of Nuclear Power

From the time of commercial operation onward, the energy flow of the nuclear plant is strongly positive. Early in the second year of operation, all energy investments have been repaid and four units of energy are returned for each energy unit required to operate the plant and all associated fuel cycle steps. Figure B-2 illustrates the net energy flows, as a function of time, for a single 1,000 MWe plant. The assumptions are the same as those contained in earlier discussions in this appendix.

By the end of 1985, 185,000 megawatts of nuclear power could be in commercial operation (see ERDA-48 scenarios). At the end of 1975, 52 nuclear plants were in commercial operation with a combined potential capacity of 37,000 megawatts. Thus, over the next 10 years on average of 15 plants per year (of 1000 MWe each) must be brought on line in order to meet the 185,000 megawatt level.

The external energy required to build, fuel, and operate these new additions to the Nation's electric system is substantial.* But the energy produced by the plants, both during pre-commercial testing and commercial operation, is much greater. Figure B-3 illustrates the net energy trend of the assumed nuclear electric system from 1973 to 1985. Each point on the curve represents the difference between the total nuclear system energy output (electrical) and the total external energy inputs (electrical plus thermal) for each year. The values for 1973, 1974, and 1975 have been adjusted to reflect actual plant operating experience. The capacity factor trend established during this period is assued to continue for the years 1976, 1977, and 1978. Thereafter, the calculations reflect the assumed capacity factor schedule listed earlier in this appendix.

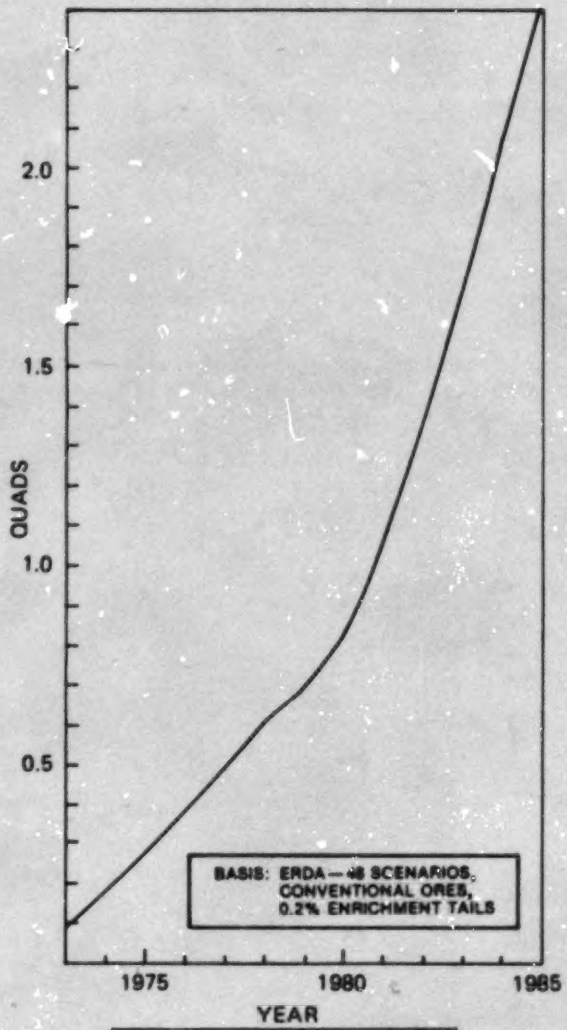


Figure B–3 Net Energy from Nuclear Power: Annual Energy Outputs Minus Annual Energy Inputs

Resource Base Analysis

This analysis requires the use of broader boundaries to include, as energy expenditures, the loss or non-use of uranium from point of extraction through the remaining steps of the fuel cycle, and the thermodynamic loss of useful energy in converting the thermal energy to electricity. The amount of initial resource required to provide a given quantity of energy reflects the ultimate potential of that resource to provide future energy needs based on current technological use patterns. For uranium, the longest non-use of resource occurs in the fissionable material which remains in the depleted uranium after the enrichment process. In addition, smaller amounts of uranium are lost in each stage of fuel cycle mining and other processing. Another major loss of resource use occurs in the nuclear generating plant where, like fossil electric plants, about one-third of the thermal energy obtained from the uranium is converted into electrical energy. Analyses performed by Development Sciences, Inc. and the State of Oregon indicate that from 6,000 to 7,000 Btu of energy resource input are required to produce 1,000 Btu of electricity.

The net energy of nuclear electric power by this measure could be substantially improved if the economics of the transformation processes were more favorable, such as by extracting more of the fissionable uranium during the enrichment process or by the more efficient use of the exhausted energy from the power plant (e.g., for process heat).

* The energy expended for plants constructed prior to 1985 but not going into commercial operation until after 1985 is also included.

Glossary

RD&D Technology Programs

Breeder Reactors

The development, design, construction, and operation of components and systems that use nuclear fuels for producing power or process heat, in which fissionable material is produced at a faster rate than it is consumed. The program focuses on the development of a liquid metal fast breeder reactor system, and is also investigating the concepts of gas-cooled, and light water breeder reactors.

Coal—Direct Utilization in Utility/Industry

The development, design, construction, and operation of advanced components, systems, and processes involved in the combustion of various types of coal; transfer of the heat produced to steam or other working fluids for process or power use; and reduction or control of the generation of pollutants during combustion. The program includes the development of new combustion methods (e.g., fluidized-bed combustion), design of more efficient boilers, and use of additives during combustion. (Stack gas cleaning technology is covered under Environmental Control Technology.)

Conservation in Buildings and Consumer Products

The development, design, construction, and operation of buildings and consumer products that minimize energy consumption. The technology includes types of insulation and fenestration and systems of control to minimize energy requirements, as well as consumer products such as appliances, televisions, and heating, cooling and ventilating systems that use less energy.

Electric Conversion Efficiency

The development, design, construction, and operation of advanced devices for converting heat to electricity. The program focuses on mechanical, electrochemical, and thermodynamic devices (e.g., fuel cell, thermionic, thermoelectric, magnetohydrodynamic, and turbine systems) that employ working fluids other than steam and combustion gas, frequently in combination with conventional cycles.

Electric Power Transmission and Distribution

The development, design, construction, and operation of systems to transport electrical energy from the generation station to the eventual utilization device. The technology includes extra-high-voltage AC, DC, underground, and cyrogenic systems, as well as system security and load management.

Electric Transport

The development, design, construction, and operation of transportation methods that use electrical energy as the source of propulsion power. The technology includes electric automobiles, trucks, and rail transport systems.

Energy Storage

The development, design, construction, and operation of advanced devices for storing energy until needed. The technology includes devices such as batteries, pumped storage for hydroelectric generation, flywheels, and compressed gas.

Fuels from Biomass

The development, design, construction, and operation of systems and processes for the conversion of biological materials to energy sources. The technology includes such processes as the conversion of wood or other plants to alcohol, and the fermentation or decomposition of organic by-product materials to produce methane or other fuels.

Fusion

The development, design, construction, and operation of systems and processes for combining or fusing particles of the lighter elements into elements of higher atomic weight as a means of producing usable power. The program is currently investigating several methods to induce fusion, including lasers and magnetic confinement systems.

Gaseous and Liquid Fuels from Coal

The development, design, construction, and operation of components, systems, and processes that will convert various types and ranks of coal to other fuel forms. These forms include clean gases of either high or low energy content; and oils and other clean liquid fuels or solid fuels that have higher heat content, less ash, and fewer impurities than natural coal. Gaseous fuels production includes both above-ground and *in situ* processes.

Geothermal

The development, design, construction, and operation of systems and components to extract and convert the heat energy contained in geological formations to power. Geothermal resources include hot rocks, dry or wet steam, hot brines with associated methane, and magma.

Hydrogen in Energy Systems

The development, design, construction, and operation of systems, components, and processes for producing, transporting, storing, and utilizing hydrogen as a substitute fuel. The technology focuses on the development of non-electrolysis processes for generating the hydrogen product from non-fossil sources and on methods for storing and transporting it.

Industry Energy Efficiency

The development, design, construction, and operation of industrial processes and equipment to minimize the energy requirements of fabricating, forming, converting, or producing industrial or agricultural products.

Nuclear Converter Reactors

The design, construction, and operation of components and systems which use nuclear fuels to produce power or process heat and which consume fissionable material at a faster rate than it is produced. The program focuses on the high temperature gas cooled reactor (HTGR) and the continued development and improvement of basic technologies associated with light water reactors (LWR). (See also Support to Nuclear Fuel Cycle.)

Oil and Gas Enhanced Recovery

The application of improved techniques, processes, and methods that permit extraction and recovery of additional amounts of oil or gas. These applications include hydraulic fracturing methods, the injection of solvents and heat to increase yield, and other advanced methods to enhance recovery.

Oil Shale

The development, design, construction, and operation of systems, components, and processes for extracting hydrocarbon products from shale and converting the product to liquid or gaseous fuels or other chemical commodities. The program includes the development of *in situ* methods for product extraction.

Solar Electric

The development, design, construction, and operation of systems to collect and transform the radiant energy of sunlight into electrical power. The technology includes the use of various collector (e.g., mirror concentrators) and conversion systems (e.g., photovoltaic devices) as well as solar-derived energy (e.g., wind or ocean thermal gradients).

Solar Heating and Cooling

The development, design, construction, and operation of systems that utilize and/or store the radiant energy of sunlight to provide comfort control and heated water for household, industrial, or agricultural use.

Transportation Efficiency

The development, design, construction, and operation of more efficient transport systems. The technology focuses on ships, planes, trucks, autos, trains, and pipelines, as well as the power systems involved.

Waste Heat Utilization

The development, design, construction, and operation of systems that use the waste or rejected heat incident to the production of electrical power or industrial products. The technology focuses on bottoming cycles as well as integrated total energy systems employed in residential, commercial, and industrial complexes.

Waste Materials to Energy

The development, design, construction, and operation of systems and processes for converting the energy contained in waste or refuse into power or heat. The technology also includes processes for recovering and recycling non-energy resources.

Broad Supporting Technologies or Programs

Basic Energy Science

A broad-based program of scientific investigation into the fundamental nature of the universe to

develop greater understanding of the nature and behavior of matter. The program includes research in the molecular, material, nuclear, and biological sciences.

Biomedical and Environmental Research

The scientific investigation of the health and environmental effects of radiation and other pollutants on the environment and its inhabitants. This program includes the study of ecological relationships and the development of systems and methods to measure the release of noxious or harmful substances.

Information Dissemination

The preparation and widespread distribution of the technical information and data developed through the energy program to encourage broad public knowledge, understanding, and application.

Manpower Development

The training and education of personnel to ensure an adequate pool of trained and knowledgeable manpower to design, construct, and operate new facilities and systems resulting from the development or commercialization of new energy technology.

Safety

The development, design, construction, and operation of systems, components, and devices to protect the public and workers from the health hazards associated with energy production and utilization. The program focuses on the development of devices and designs to prevent accidents or to mitigate the consequences of potential accidents.

Systems Studies

The development and application of methods and techniques for analyzing and assessing programs, activities, and projects to review and assess efforts to date and to determine future courses and directions. These studies include cost/benefit analysis, environmental impact analysis, assessment of the likelihood of technical success, forecasts of possible futures resulting from specific actions, and guidance for energy program planning and implementation.

Specific Supporting Technologies

Environmental Control Technology

The development, design, construction, and demonstration of processes and systems to control the amount and type of pollutants discharged into the environment as a result of energy conversion, extraction, or use. The technology includes such systems as scrubbers, filters, washers, and precipitators to remove noxious gases or particulates from combustion processes; methods to control or remove radioactive gases or particulates from nuclear processes; converters to modify exhaust from automobile engines; and cooling towers and other means to permit the dissipation of waste heat with minimum adverse environmental impact.

Exploration and Resource Assessment

The development and application of advanced technologies to locate, identify, and assess the amounts and types of energy resources or other useful material in geological formations. The technologies include such methods as magnetic and gravimetric measurement, seismic and acoustic scanning, aerial and space photography, drilling, and sample analysis, as well as the compilation, analysis, and reporting of resource data.

Fossil Fuel Transportation

The development, design, construction, and operation of advanced systems and components to transport fossil fuels from point of origin to point of use. The technology focuses on such systems as unit trains, pipelines, and conveyor systems.

Mining and Beneficiation

The design, construction, and operation of systems and processes to extract useful resources from geological formations, and the development of techniques and methods to concentrate or upgrade ores to a higher content of the desired material. The technology includes both underground and surface extraction techniques.

Nuclear Safeguards

The development, design, construction, and operation of systems, methods, and devices to account for and control nuclear materials, and to prevent sabotage, theft, or other uses that could threaten life or property.

Support to the Nuclear Fuel Cycle

The development, design, construction, and operation of facilities, systems, components, and processes to recover fissionable material from the chemical processing of spent nuclear fuels from power reactors, and to refabricate that material into fuels for reinsertion into the reactor systems. The technology focuses on the management and control of the radioactive waste produced incident to the recovery of fissionable material, and is applied to light water reactors, gas-cooled reactors, and breeder reactor systems.

Uranium Enrichment

The development, design, construction, and operation of systems, processes, and components to permit isotopic separation and enrichment of the isotope U-235 in uranium for use as nuclear fuel. The technology includes such processes as gaseous diffusion, centrifugation, and advanced systems involving lasers and aeronozzles.

Waste Management

The development, design, construction, and operation of systems and components to permit the safe management, transport, storage, and eventual disposal of radioactive wastes in an environmentally acceptable, nonhazardous manner. The technology also includes the management of noxious wastes resulting from the use of other energy resources.

SELECTED BIBLIOGRAPHY

Averitt, Paul, "Coal Resources of the United States: 1974," *U.S. Geological Survey Bulletin 1412*, GPO,* 1975.

Brobst, Donald A., and Walden P. Pratt, ed., *United States Mineral Resources*, Geological Survey Professional Paper 820, GPO, 1973.

"Changes Restructuring World Oil," *Oil and Gas Journal*, 72(52): 105–110, December 30, 1974.

Culbertson, W. C., and J. K. Pitman, "Oil Shale," *United States Mineral Resources*, Geological Survey Professional Paper 820, GPO, 1973.

Darmstadter, J., and H. Landsberg, "The Economic Background," *Daedalus: The Oil Crisis in Perspective* (special issue dedicated to this topic), 104, Fall 1976.

Department of the Interior, News Release, May 7, 1975.

Development Sciences, Inc., *A Study to Develop Energy Estimates of Merit for Selected Fuel Technologies*, prepared for U.S. Department of the Interior, Office of Research and Development, September 23, 1975.

Doernberg, A., "Comparative Analysis of Energy Use in Sweden and the United States," Brookhaven National Laboratory, 1975.

ERDA, Division of Electric Energy Systems, *The Energy Related Applications of Helium*, ERDA-13, NTIS,** 1975.

ERDA, Division of Solar Energy, *National Program for Solar Heating and Cooling (Residential and Commercial Application)*, ERDA-23A, TIC,*** 1975.

ERDA, Office of Planning and Analysis, *A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future*, ERDA-48, Volume 1: The Plan, Volume 2: Program Implementation, GPO, 1975.

ERDA, Office Planning and Analysis, *First Public Meeting on A National Plan for Energy Research, Development and Demonstration, Synopsis of Proceedings*, ERDA-48 (N-1), Atlanta, Georgia, October 20–21, 1975.

ERDA, Office of Planning and Analysis, *Second Public Meeting on A National Plan for Energy Research, Development and Demonstration, Synopsis of Proceedings*, ERDA-48(H-2), Seattle, Washington, December 2–3, 1975.

ERDA, Division of Solar Energy, *Definition Report: National Solar Energy Research, Development and Demonstration Program*, ERDA-49, TIC, 1975.

ERDA, Division of International Security Affairs, *Energy Policies in the European Community*, ERDA-51, NTIS, 1975.

ERDA, Compiled by ERDA Library, *World Energy Resources: An Annotated Bibliography of Selected Material on the Availability and Development of World Energy Resources*, ERDA-53, GPO, June 1975.

ERDA, *Uranium Enrichment: A Vital New Industry*, ERDA-85, 1975.

ERDA, *Division of Geothermal Energy Definition Report: Geothermal Energy Research, Development and Demonstration Program*, ERDA-86, NTIS, 1975.

ERDA, Division of Laboratory and Field Coordination, *Report of the Field and Laboratory Utilization Study Group* (and Appendix), ERDA-100, 1975.

ERDA, Division of Biomedical and Environmental Research, *Federal Inventory of Energy Related Biomedical and Environmental Research for FY 1974 & FY 1975*, ERDA-110, Washington, D.C., Volumes 1–5, 1975.

ERDA, Office of Fossil Energy, *Coal Gasification*, Quarterly Report, ERDA-111, GPO, January–March 1975.

ERDA, Office of Fossil Energy, *Coal Demonstration Plants*. Quarterly Report, ERDA-112, GPO, January–March 1975.

ERDA, Office of Fossil Energy, *Power and Combustion*, Quarterly Report, ERDA-113, GPO, January–March 1975.

ERDA, Office of Fossil Energy, *Coal Liquefaction*, Quarterly Report, ERDA-114, GPO, January–March 1975.

Federal Energy Administration, Project Independence, *Project Independence Report*, GPO, November 1974.

Federal Register, 40 (229), November 26, 1975.

Franssen, Herman T., *Towards Project Interdependence: Energy in the Coming Decade*, prepared for the Joint Committee on Atomic Energy, U.S. Congress, 94th Congress. 1st Session, 1975.

Goen, Richard L., and Ronald K. White, *Comparison of Energy Consumption Between Germany and the United States*, Stanford Research Institute, 1975.

Hoffman, K. C., *A Methodology of Technical Analysis with Application to Energy Assessment*, ASME Paper 75-WA/TS-8, American Society of Mechanical Engineers, New York, 1975.

* Available from the Government Printing Office, Washington, D.C.

** Available from the National Technical Information Service, Springfield, Virginia.

*** Available from the Technical Information Center, Oak Ridge, Tennessee.

Hudson, Edward A., and Dale W. Jorgenson, "U.S. Energy Policy and Economic Growth, 1975–2000," *The Bell Journal of Economics and Management Science*, 5(2): 461–514, Autumn 1974.

Institute for Energy Analysis, Oak Ridge Associated Universities, *Net Energy from Nuclear Power*, IEA-75-3, November 1975.

Kastrop, J. E., "Potential Impact of Tertiary Oil Recovery," *Petroleum Engineer*, 47 (12): 21/23, November 1975.

Lawrence, Carl J., and Q. L. Farrar, "Supply Problems, Technical Developments Tackled by WPC," *The Oil and Gas Journal*, 73 (21): 57–68, May 26, 1975.

Linden, Henry R., *Draft Report*, Institute of Gas Technology, 1975.

McKelvey, V. E., "World Energy Reserves and Resources," *Public Utilities Fortnightly*, 96(7): 27–33, September 25, 1975.

"Middle East Oil Reserves," *The Petroleum Economist*, 42(10): 369–371, October 1975.

Miller, Betty M., Harry L. Thomsen, Gordon L. Dolton, Anny B. Coury, Thomas A. Hendricks, Frances E. Lennartz, Richard B. Powers, Edward G. Sable, and Katharine L. Vornes, *Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States*, Geological Survey Circular 725, Reston, Virginia, U.S. Geological Survey, 1975.

Oklahoma, University of, Science and Public Policy Program, *Energy Alternatives: A Comparative Analysis*, GPO, 1975.

Oregon, State of, Office of the Governor, Office of Energy Research and Planning, *Transition*, January 1975.

Pilati, David A., and Ralph P. Richard, *Total Energy Requirements for Nine Electricity-Generating Systems*, CAC Document No. 165, Center for Advanced Computation, University of Illinois, 1975.

"Productive Capacity Grows as World Demand Falters," *World Oil*, 181(3): 41–44, August 15, 1975.

Turner, Louis, "The Political Implications of North Sea Oil and Gas," *Energy Policy*, 3(2): 158–159, June 1975.

United States Congress, Office of Technology Assessment, *An Analysis of the ERDA Plan and Program*, Washington, D.C., 1975.

White, D. C., and D. L. Williams, ed., *Assessment of Geothermal Resources of the United States—1975*, Geological Survey Circular 726, Reston, Virginia, U.S. Geological Survey, 1975.

World Energy Conference, *Survey of World Energy Resources, 1974*, New York, 1975.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1976—0-201-877